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SOIL SCIENCE

JACOB G. LIPMAN, Editor-in-Chief
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A MONTHLY JOURNAL DEVOTED TO PROBLEMS IN SOIL PHYSICS, SOIL CHEMISTRY AND SOIL BIOLOGY

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THE SIZE DISTRIBUTION OF PARTICLES IN SOILS AND THE EXPERIMENTAL METHODS OF OBTAINING THEM

A REVIEW[1]

SVEN ODÉN

Royal Institute of Technology, Stockholm

Received for publication May 14, 1924

INTRODUCTION

The methods of mechanical soil analysis in their various forms are undoubtedly among the more tedious operations with which soil scientists are confronted. The experimental methods are not very precise, and there is little uniformity with regard to the limits of size of the various *groups* or *fractions* into which the soil particles are divided. It is not surprising therefore, that there have been many proposals to introduce, instead of mechancial composition, some other characteristic quality which could be more easily measured and which had some relation to the composition, e.g., hygroscopicity "Benetzungswärme" (Mitscherlich (14, 15)) or cohesion and plasticity (Atterberg (1, 2, 3)). None of these alternatives has been very successful, because the qualities were neither precisely defined nor could they be brought into definite relation to the mechanical composition. The discrepancy between soil surface and Mitscherlich's hygroscopicity has been emphasized by P. Ehrenberg (5, 6) and experimentally demonstrated by the writer (21) and lately by F. Zunker (41). It cannot be denied that there is something fundamental in the old grouping of soils into *sands*, *loams*, and *clays*, and that many of the important properties from the agricultural point of view, e.g., water-retaining capacity, extent and speed of capillary rise, drainage removal, etc., are mainly dependent on the mechanical composition, the determination of which, therefore, still remains essential.

But there is still little agreement among the various groups into which different workers from different countries have divided the mineral particles. This is illustrated by figure 1, and also by table 1, where the figures obtained for an arbitrary soil according to the different modes of division are recorded. Not only is the discrepancy among the groups an inconvenience, but "the method is fundamentally defective in that the grouping is quite arbitrary, sharp lines being drawn where none exist in Nature, and the soil is represented

[1] The essential parts of this paper were presented before the British Association for the Advancement of Science at the Liverpool meeting, September, 1923.

as a mixture of five or six different substances, when in point of fact the number of components is indefinitely large" (Russel (30)).

In order to avoid an arbitrary grouping of the soil particles and to facilitate the transition from one system to another, I tried (16) in 1915 to introduce the

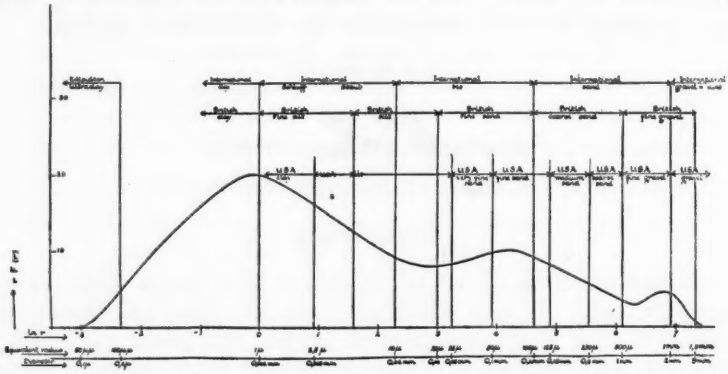


FIG. 1. DIAGRAM SHOWING COMPARISON OF UNITS OF MECHANICAL ANALYSIS OF SOILS IN DIFFERENT COUNTRIES

TABLE 1

Mechanical analysis of a soil, showing various figures for the same soil, according to the various units

INTERNATIONAL GROUP	PARTICLE-GROUP	INTERNATIONAL SYSTEM	BRITISH SYSTEM	U. S. A. SYSTEM
	Gravel	1.2		1.2
Sand	Fine gravel	11.7	4.1	2.9
	Coarse sand		9.2	2.5
	Medium sand			4.1
Mo	Fine sand	20.6	14.5	8.7
	Very fine sand			6.1
Schluff	Silt	33.3	12.6	24.7
	Fine silt		25.3	
Clay	Clay	31.9	34.3	49.8
	Colloidal clay	1.3		
		100.0	100.0	100.0

Maxwellian conception of the *distribution* according to size, i.e., to obtain a characteristic curve by plotting as abscissae some quantity related to size, against some quantity related to the amount corresponding to every size.

This conception has been adopted by several workers on soils and suspensions in general and a special method "Sedimentation-analysis" has arisen.

In the following treatise my intention is to develop the general theory for these methods and by the way of example give a review of existing practical methods up to 1924 without entering into any detailed descriptions which the reader will find in the appended bibliography. The methods in use in my own laboratory as demonstrated at the Fourth International Congress of Pedology at Rome will be described in some more detail.

As in actual measurements the soil particles are allowed to fall as a sediment in a liquid, it seemed natural to introduce the conception of an "equivalent radius," on the assumption of the applicability of Stokes' law for the fall of particles through a liquid. This involves a certain theoretical assumption which, as Prof. C. G. Knott (12), first showed, is not strictly necessary. Though the "equivalent radius" is of great value for the image it gives us of the size of the soil particles, it has in this paper been introduced only as a secondary variable, whereas as the size-variable chosen has been the velocity of the fall,[2] this quantity being free from theoretical suppositions.

There is no difficulty in reconverting the figures showing "velocity" into "equivalent radius" on the assumption of Stokes' law. Having once established the distribution curve in one way or the other, it is also easy to obtain the figures for any of the arbitrary groups (table 1). This curve gives a more accurate picture of the character of the soil than it is possible to obtain by elutriation and sedimentation methods, and may be obtained more easily and with greater accuracy than could be secured by the older method.

MATHEMATICAL THEORY[3]

At first, a mathematical discussion of the various general methods available for the determination of the distribution curve is necessary and has the advantage of affording a natural basis for the classification of existing methods. Thus we have to look for *those properties* of a suspension which are functions of the size distribution of the particles. As all the methods are based upon observations made on the settling of particles from a suspension, it will be assumed throughout that at the beginning the soil particles are uniformly dispersed in the liquid, say water, and that no aggregation or coagulation phenomena occur. This will not always be the case but the convenient treatment of the soil in order to obtain and maintain the single grain-structure has been discussed elsewhere (19).

If we thus by z denote the fraction of the particles which fall with a velocity less than v; then z varies from zero to unity when v changes from the least to the greatest value.

If we also define a function U as

$$U = \frac{dz}{dv} \tag{1}$$

[2] This is in accordance with Robinson's proposals (29).

[3] This theory is developed in more detail in papers by Odén (17) and Odén and Fisher (22).

then it is clear that by integrating this function between two values, of the velocity, v_1–v_2, we shall obtain the fraction of the particles whose velocities fall between these limits: thus

$$\int_{v_1}^{v_2} U\,dv = \int_{v_1}^{v_2} \frac{dz}{dv}\,dv = Z_{v_2} - Z_{v_1}$$

The *distribution* curve may be drawn with reference to the coördinates v and U. But for the soil particles, v measured in $\frac{\text{cm.}}{\text{sec.}}$ may vary from 0.9×10^{-6} to 400. For reason of convenience it is therefore better to use the values of $\log_e v$ as abscissae for the distribution-curve, instead of v. Since

$$dz = U\,dv$$
$$= v\,U \cdot d\,(\log_e v)$$

it is obvious that we must in this case employ the function $v\,U$ for ordinates to the distribution curve, in order that its area may represent the same physical quantity as when v and U act as abscissae and ordinates, respectively. Thus, in the following, when distribution curves are mentioned, this will refer to the curve whose coördinate axes X and Y are such that:

$$X = \log_e v \tag{2}$$
$$Y = vU$$

Now consider a soil suspension which is assumed to satisfy the following conditions:

1. Complete dispersion of the soil particles, and prevention of any tendency to coagulation.
2. Uniform distribution of the particles at the beginning, t_o of the measurements.
3. Constant temperature, so that no convection currents and disturbances occur during the sedimentation.
4. A concentration so dilute that the particles do not interfere with one another during their fall through the liquid, and the density of the suspension will never differ very greatly from that of the pure liquid.

Let G be the total weight of particles suspended in a volume V of the liquid (water), and σ the specific gravity of soil particles. Let φ be the specific gravity of the soil suspension at a depth x from the surface.

At the time t_o, every cubic centimeter of the suspension contains G/V gm., or $G/V\sigma$ cc. of solid particles, and therefore $\left(1 - \frac{G}{V\sigma}\right)$ cc. of water. The specific gravity of the suspensions at the beginning therefore is

$$\varphi_0 = 1 - \frac{G}{V\sigma} + \frac{G}{V} = 1 + \frac{G}{V}\left(1 - \frac{1}{\sigma}\right) \tag{3}$$

At the time t and depth x, there will remain zG gm. of particles per V cc.; for all those with velocity $v > \frac{x}{t}$ will have left the layer, and those for which $v < \frac{x}{t}$ will remain in the same concentration as at the beginning (cf. fig. 2). Hence,

$$\varphi = 1 + \frac{zG}{V\sigma}\cdot(\sigma - 1)$$

$$\text{or } \varphi = 1 + cz \tag{4}$$

Where $c = \frac{G\,(\sigma-1)}{V\sigma}$ is a constant under given experimental conditions. If a be the area of the base of the column of suspensions then

$$V = ax,$$

$$\text{and } cx = \frac{1}{a}\cdot\frac{G(\sigma-1)}{\sigma} = \frac{1}{a}\cdot G\left(1 - \frac{1}{\sigma}\right) \tag{5}$$

The right-hand side of this expression is obviously the weight of the particles which ultimately settle on the unit area of the base of the column weighed *in the liquid;* if A_∞ represents the total weight (in the liquid) of particles deposited in a very long time,

$$\text{thus} \qquad cx = \frac{A\infty}{a} \tag{6}$$

From the preceding equations, we can develop the theory of the various methods which may be employed in order to obtain the distribution curve. Whereby we also make use of the obvious connection

$$v = \frac{x}{t} \tag{7}$$

$$dv = \frac{1}{t}\,dx - \frac{x}{t^2}\,dt$$

$$\frac{\partial v}{\partial x} = \frac{1}{t} \tag{8}$$

and

$$\frac{\partial v}{\partial t} = -\frac{x}{t^2} \tag{9}$$

I. Measurements of the variation of density

By equation (4) we have that

$$\varphi = 1 + cz$$

$$\therefore d\varphi = c\left(\frac{\partial z}{\partial x}\,dx + \frac{\partial z}{\partial t}\,dt\right)$$

A. Suppose that the densities of the column at various depths are observed simultaneously; then $dt = 0$ and

$$\frac{\partial \varphi}{\partial x} = c\frac{\partial z}{\partial x}$$

$$= c\frac{\partial z}{\partial v}\cdot\frac{\partial v}{\partial x}$$

and from equation (7),

$$\therefore \frac{\partial \varphi}{\partial x} = \frac{c}{t}\cdot\frac{\partial z}{\partial v}$$

$$= \frac{c}{vt}\cdot v\frac{\partial z}{\partial v}$$

Using equation (2)

$$\therefore \frac{\partial \varphi}{\partial x} = \frac{c}{x}\cdot Y \text{ or } Y = \frac{x}{c}\frac{\partial \varphi}{\partial x} \tag{10}$$

From equations (7) and (10), X and Y can be obtained, and the distribution curve related to velocity constructed.

B. Suppose that the density of the suspension at a given depth is measured at various times; then $dx = 0$, and

$$\frac{\partial \varphi}{\partial t} = c\frac{\partial z}{\partial t}$$

$$= c\frac{\partial z}{\partial v}\cdot\frac{\partial v}{\partial t}$$

$$= -\frac{cx}{t^2}\cdot\frac{\partial z}{\partial v}; \qquad x = vt$$

$$= -\frac{cv}{t}\cdot\frac{\partial z}{\partial v}$$

$$\therefore \frac{\partial \varphi}{\partial t} = -\frac{c}{t}Y \text{ or } Y = -\frac{t}{c}\frac{\partial \varphi}{\partial t} \tag{11}$$

Which is another equation from which the ordinates Y of the distribution curve can be calculated.

II. Measurements of the variation of hydrostatic pressure

Let π denote the hydrostatic pressure at a depth x in the suspension at any time t. Then

$$\int_0^x \varphi\, dx = \pi$$

$$\therefore \frac{d\pi}{dx} = \varphi \tag{12}$$

A. Regarding t as a constant, and differentiating, again with respect to x, we have

$$\frac{\partial^2 \pi}{\partial x^2} = \frac{\partial \varphi}{\partial x}$$

and from equation (10),

$$\therefore Y = \frac{x}{c} \cdot \frac{\partial^2 \pi}{\partial x^2} \tag{13}$$

At a constant time t, each depth x corresponds to a definite velocity $\left(v = \frac{x}{t}\right)$, and the appropriate value of $\frac{\partial^2 \pi}{\partial x^2}$ from which the distribution curve can be obtained according to equation (13).

B. From equation (12),

$$\frac{d\pi}{d(vt)} = \varphi$$

and at any given time,

$$\therefore \frac{d\pi}{\partial v} = t\varphi$$

Hence, we have that

$$\frac{\partial v}{\partial \pi} = \frac{1}{t\varphi}$$

or

$$\frac{\partial}{\partial \pi}\left(\frac{x}{t}\right) = \frac{1}{t\varphi}$$

It has been assumed so far that t is a constant, but suppose now that we restrict our attention to one particular layer of depth x, and make observations at various times. From the last equation, we obtain

$$-\frac{x}{t^2} \cdot \frac{\partial t}{\partial \pi} = \frac{1}{t\varphi}$$

or

$$\frac{\partial \pi}{\partial t} = -\frac{\varphi x}{t}$$

$$\therefore \frac{\partial \pi}{\partial t} = -v\varphi$$

For particles corresponding to each value of Y, v will be constant, and therefore we may write

$$\frac{\partial^2 \pi}{\partial t^2} = - v \cdot \frac{\partial \varphi}{\partial t}$$

and, hence, we obtain from equation (11)

$$Y = \frac{t^2}{cx} \cdot \frac{\partial^2 \pi}{\partial t^2} \tag{14}$$

If the second derivative of the hydrostatic pressure is measured at different times, it is possible to calculate the distribution curve by means of this equation.

III. Measurement of change in weight of an immersed body

Consider a cylinder, of cross-sectional area f, whose weight in air is W, and which is counterpoised in the suspension at any given time by a weight A so that the upper end is above the surface of the liquid. As the density of the suspension decreases, on account of the removal of the particles by sedimentation, A will increase, and the distribution curve can be deduced in terms of the second derivative of A with respect to time. For

$$A = W - f\pi$$

$$\therefore \frac{\partial A}{\partial t} = -f \frac{\partial \pi}{\partial t}$$

$$\frac{\partial^2 A}{\partial t^2} = -f \frac{\partial^2 \pi}{\partial t^2}$$

and, substituting in equation (14), we obtain

$$Y = -\frac{t^2}{cxf} \cdot \frac{\partial^2 A}{\partial t^2} \tag{15}$$

IV. Measurement of weight of sediment deposited from a suspension

Finally, we may measure the rate of accumulation of sediment on a plate suspended x cm. from the surface, and of area a. From equation (6), it is seen that

$$cxa = A_\infty$$

so that equation (14) may be written

$$Y = \frac{t^2}{A_\infty} \cdot \frac{\partial^2 \pi}{\partial t^2} \cdot a$$

The pressure exerted on the pan at a time t is due to a column of water of height x, and the downward force exerted by the particles remaining in suspension and not deposited on the pan thus,

$$\pi = x + \frac{A\infty - B}{a}$$

where B = the weight of particles deposited on the pan.

A small correction is necessary, because in practice we determine the weight of the deposit on the pan in the suspension, and not in water. The term $A\infty$ requires no correction, however, because when t passes towards $\rightarrow \infty$ all the particles will have left the suspension, and only water (density $= \varphi = 1$) will remain.

$$\therefore A = W_1 - \frac{W_1\varphi}{\sigma}$$

and, similarly,

$$\left.\begin{aligned} \therefore A &= \frac{\sigma - \varphi}{\sigma} W_1 \\ B &= \frac{\sigma - 1}{\sigma} W_1 \end{aligned}\right\} \therefore B = \frac{\sigma - 1}{\sigma - \varphi} A$$

$$\therefore \pi = x + \frac{A\infty}{a} - \frac{A}{a} \cdot \frac{\sigma - 1}{\sigma - \varphi}$$

Differentiating with respect to t, and substituting in equation (14), we obtain:

$$\therefore Y\left(1 - \frac{2ct}{A\infty} \cdot \frac{\sigma - 1}{(\sigma - \varphi)^2} \cdot \frac{\partial A}{\partial t} + \frac{cA}{A\infty} \cdot \frac{\sigma - 1}{(\sigma - \varphi)^2}\right) - \frac{ct}{A\infty} A \frac{\sigma - 1}{(\sigma - \varphi)^2} \cdot \frac{\partial Y}{\partial t}$$

$$+ \frac{2c^2}{A\infty} A \frac{\sigma - 1}{(\sigma - \varphi)^3} \cdot Y^2 = - \frac{t^2}{A\infty} \cdot \frac{\sigma - 1}{\sigma - \varphi} \cdot \frac{\partial^2 A}{\partial t^2} \qquad (16)$$

Inspection of equation (16) will show that for all cases of practical importance, all the terms on the left-hand side are small, except the first, and since φ never differs appreciably from unity for a dilute suspension, we may write, to a very close approximation

$$Y = - \frac{t^2}{A\infty} \frac{\partial^2 A}{\partial t^2} \qquad (17)$$

This equation provides by far the most accurate method for determining Y, and this was the first equation whose practical application was utilized to obtain the distribution curve as will be shown below.

TRANSITION FROM "VELOCITY" TO "EQUIVALENT RADIUS"—STOKES' EQUATION

This transformation involves the application of the famous equation of Sir G. G. Stokes (33, 34) which is in accordance with Robinson's proposals (29):

$$v = \frac{2}{9} g \frac{\sigma - \sigma_1}{\eta} r^2 \tag{18}$$

$$v = Cr^2 \tag{18b}$$

$$r = \sqrt{\frac{v}{C}} = \sqrt{\frac{x}{Ct}} = K\sqrt{\frac{x}{t}} \tag{18c}$$

where $K = \sqrt{\frac{1}{C}}$

where:

v = rate of fall
g = gravitational acceleration
r = (equivalent) radius of the particle
σ_1 = density of the liquid (for water = 1)
σ = density of the particle
η = viscosity of the liquid

Stokes' formula has been proved experimentally to be accurate for small spheres if:

1. The particles are great compared with the molecules of the fluid.
2. The extent of the fluid is great compared with the size of the particle.
3. The particles are rigid and smooth.
4. No slip occurs between particle and fluid.
5. The velocity does not exceed a certain critical value which for silica spheres was found to be 2.5 cm./sec. corresponding to a radius of 85μ.

The formula has been extended by C. W. Oseen (25, 26) to comprise also larger particles and for non-spherical particles very complicated formulae have been suggested by J. Boselli (4), R. Gans (7), K. Przibram[4] and others. But as we in soils have to deal with particles of various kinds and shapes, no general formula can be used, and it is useful to introduce the conception "effective radius" or "equivalent radius." This is defined as the radius of a perfect sphere of the same material which sinks through the fluid at the same average rate as the particle in question. If the particles were perfect spheres the relation between the sinking velocity and the radius would be equation (18), but for various shapes there will be some discrepancy. As long as we are not dealing with needles or thin plates the equivalent radius will give a fairly good idea of the size of the particles. The constant C which may be called Stokes' constant has been calculated for soil particles at various temperatures on the assumption that the specific gravity is 2.7. From Stokes' equation compared with table 2, it will be seen that η, and consequently C, vary considerably with the temperature. From 25° to 10° the variation in η is 46 per cent, in C 31.5 per cent, and in K = 20.8 per cent. This is the

[4] Kaiserl. Akad. d. Wissensch. in Wien. Sitzungsber. d. Mathem-Naturn. Klawe *121*, Abt. II A (1912).

reason why the results given by "Mechanical analysis" are so often untrustworthy, but the variations can be accounted for by means of the data in table 2. Differentiating Stokes' equation (18 b) we obtain

$$dv = 2\,Cr \cdot dr \qquad \text{and}$$

$$\frac{dv}{v} = \frac{2\,dr}{r}$$

$$d\,(\log_e \cdot v) = 2\,d\,(\log_e \cdot r)$$

or if we take directly the logarithms

$$\log_e v = 2 \log_e r + \log_e C$$

TABLE 2

Variation of η and C with the temperature

TEMPERATURE	$\eta \times 10^6$	C	$K \times 10^3$
°C.			
10	1307	28,355	5,939
11	1271	29,158	5,856
12	1235	30,007	5,773
13	1202	30,834	5,695
14	1171	31,648	5,621
15	1140	32,509	5,546
16	1110	33,388	5,473
17	1082	34,252	5,403
18	1055	35,128	5,335
19	1029	36,016	5,269
20	1004	36,913	5,205
21	980	37,816	5,142
22	957	38,725	5,082
23	936	39,594	5,026
24	915	40,503	4,969
25	895	41,408	4,914

Thus, if we substitute half the values for the abscissae in the distribution curves having $\log_e v$ as abscissae (which simply means altering the scale) we may keep the ordinates unaltered, and thus obtain the distribution curve having as coördinates Y and $\log_e r$; or we may keep the abscissae unaltered and according to the relationship

$$2\,Y = r \cdot F\,(r) \tag{19}$$

double the ordinates. $F\,(r)$ here means the distribution-function when the equivalent-radii are abscissae. Thus $F\,(r)\,dr$ means the amount of particles in the radii-interval dr.

GEOMETRICAL AND GRAPHICAL SOLUTIONS

The essential of the mathematical deductions yielding the equations (14) and (17) may be obtained in a very simple manner in the following way which for practical soil work often may be sufficiently accurate (16, 41).

Suppose then, as before, that there is complete disaggregation and uniform distribution of the particles at the time of beginning the experiment t_o and that the fall of each particle is independent of the others. If all particles were of the same size they should sink with the same velocity and the concentration of the particles in a certain layer D (fig. 2) would be constant up to a certain time t_n since all disappearing particles are replaced by others coming from the layers above. Then suddenly it would drop to zero at a time t_n when the

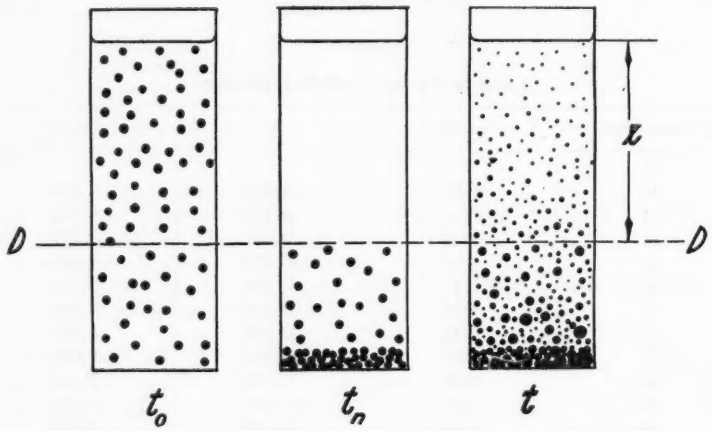


FIG. 2. DIAGRAM ILLUSTRATING FALL OF SOIL PARTICLES IN SUSPENSION

particles of a velocity $\frac{x}{t_n}$, which at the beginning were in the top layer, had passed the level D.

If again the particles are of various sizes and therefore fall with different velocities, certain groups in time disappear completely from a certain layer and the concentration there decreases continuously while the sedimentation proceeds.

Now consider a layer at the distance x from the surface and at the time t from the beginning of the sedimentation.

Of all the particles of various size some groups have *completely* passed below this level and dropped down in the receptacle, namely, those whose velocity is $> \frac{x}{t}$ (let us call these G) while from the other groups with velocities $< \frac{x}{t}$ there has been a constant flow of particles during the whole time t altogether proportional to the time and concentration (let us call this portion S).

If in figure 3 we let the ordinates of the curve OAU represent the percentage amount of particles $(G + S)$ that have passed this level (thus in relation to the total sedimented quantity, A or $y = \frac{A \cdot 100}{A\infty}$) as a function of time as abscissae thus $y = A\ (t)$, then evidently $100 - A\ (t)$ or an ordinate drawn downward from VU will be proportional to the quantity of particles suspended above this level.

Let us now draw a tangent to the curve through the point A corresponding to the time t and through the point A_1 likewise on the curve and at an infinitesimally small distance before the time t a line AD parallel to the ordinate-axis and likewise AC parallel to the abscissa-axis.

From construction and figure it follows that:

$$\frac{BC}{AC} = \frac{A_1D}{AD} = \frac{\Delta A}{\Delta t}$$

But AC corresponds to the time during which the smaller size-groups have continually passed the level D (fig. 2) and $\frac{\Delta A}{\Delta t}$ is the quantity which passes per unit of time if we neglect the coarser ones already settled.

$BC = AC \frac{\Delta A}{\Delta t} = t \frac{\Delta A}{\Delta t}$ thus represents just the quantity of the smaller groups which has passed the level D at the time t.

But OC corresponds to the total amount of particles which have passed the level and $OC = BC + OB$. Thus OB, or the distance from the point of intersection with the y-axis of the tangent (drawn through the ordinate corresponding to the abscissa t) represents the sum of those particles above a certain equivalent radius r_t that have completely passed the level, where r_t is defined by the equation

$$r_t = K \sqrt{\frac{x}{t}} \qquad (20a)$$

Repeating this for another t value we obtain another section porportional to all particles down to another r_{t_1} value

$$r_{t_1} = K \sqrt{\frac{x}{t_1}} \qquad (20b)$$

The *difference* between these sections is evidently equal to the amount of particles in the particle interval r_t to r_{t_1} and by repeating this procedure we obtain the amount of particles between two equivalent radii as the distance between the points of intersection of the corresponding tangents on the Y axis, when each tangent is laid through the points of the curve corresponding to t_1 and t_2, respectively

$$t_1 = \frac{K^2 x}{r_1^2} \quad \text{and} \quad t_2 = \frac{K^2 x}{r_2^2}$$

$$t_1 = \frac{x}{C r_1^2} \quad \text{and} \quad t_2 = \frac{x}{C r_2^2}$$

It is worth observing that the "accumulation curve" of equation (17) and the "height-difference curve" of equation (14), are identical if all A and h values are expressed in fractions, the former of the ultimate value $A\,\infty$, the latter of the initial value h_0, and that the former is the image of the latter in an imaginary plane through VU. (cf. fig. 3.)

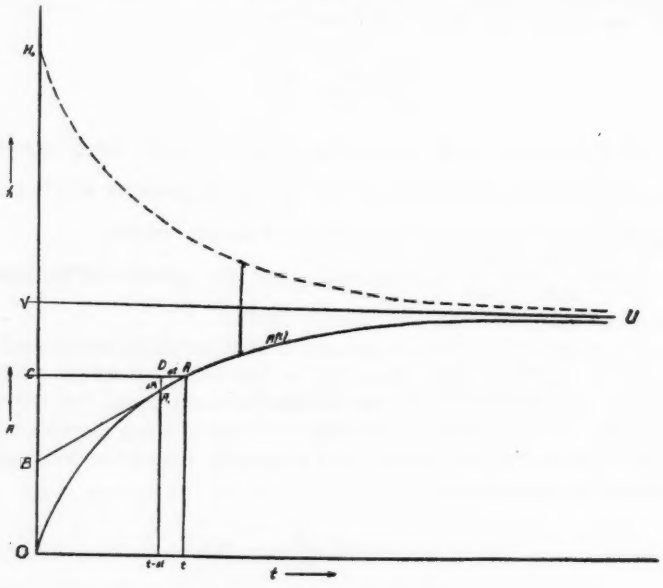


FIG. 3. DIAGRAM OF GRAPHICAL SOLUTION

It is of course quite easy to calculate at first the value of Stokes' constant C and $K = \sqrt{\frac{1}{C}}$ from the specific gravity of the particles σ, dispersion medium σ_1 and viscosity of the latter, and then to calculate the r-values corresponding to increasing t-values from the equation

$$r = K\sqrt{\frac{x}{t}}$$

since x is a constant specific to the instrument. But for practical purposes it is quite useful, according to Zunkers' proposals, to define a quantity independent of size and dimensions. Thus the "Grundfallzeit," T_0, means the

time of fall in seconds for a particle of 1 mm. diameter (equivalent radius 500 μ) falling through a distance of 1 meter in water, the temperature and viscosity of which may vary as also the specific gravity of the particle.

From this "Grundfallzeit" the "Meterfallzeit" T_r, or the time of fall for a particle of size $r\,\mu$ or R mm., may be obtained according to Stokes' law through the equation

$$T_r = T_0 \cdot \frac{10^6}{4r^2}$$

or

$$T_r = T_0 \cdot \frac{1}{4R^2} \tag{21}$$

and the time of fall t for any distance x cm. from the relations

$$t = T_r \cdot \frac{x}{100} = T_0 \frac{x}{400\,R^2} \tag{21b}$$

or

$$R = \frac{1}{20} \cdot \sqrt{\frac{x \cdot T_0}{t}} \tag{21c}$$

For a certain material we therefore have only to calculate the "Grundfallzeit" T_0 at the given temperature of the experiment, and then to draw tangents through certain points of the "Pressure curve" or "accumulation curve." The corresponding abscissae (t) will give us the equivalent radius according to (21 c) and the intercepts on the Y axis give us the amount between those radii.

Similar graphical solutions may be made on the basis of the other equations. If we by way of example choose equation (11) this may be interpreted as follows. If we draw a curve ABC (fig. 4) with time as abscissae and the experimentally obtained φ values as ordinates, and through consecutive points of this curve, e.g., B, draw tangents BD, then the section DE will be equal to $-t\frac{\partial \varphi}{\partial t}$, and by dividing by the c constant we obtain the Y values of the distribution curve corresponding to the velocities $v = \frac{x}{t}$.

REVIEW OF EXISTING EXPERIMENTAL METHODS

The first attempt to estimate the weight of an unlimited number of fractions of decreasing sinking velocity is due to Th. Schloesing, Sr. in a remarkable paper (31) which appeared 20 years ago but which seems to have been nearly unobserved by subsequent investigators.

Schloesing's experimental arrangement (fig. 5), consists in carrying away the deposits which accumulate at the bottom of a separating funnel A, by means of a slow current of water. The soil suspension is shaken and poured into the vessel A.

The orifice d of this funnel is at the same level as the surface at n, and each drop which falls from the Mariotte's flask F causes some fresh water to enter the top of the funnel and some turbid water to leave at d, the latter carrying away the deposit and collecting it in small boxes E 1, 2, 3, 4, which are moved by a clock-work.

It is evident, as Schloesing himself stated, that this arrangement contains several errors of importance. Some sediment adheres to the walls of the funnel at the bottom and is not carried away; further, the liquid which carries the sediment away is not water but suspension and contains a certain amount of smaller particles, etc. Schloesing's theoretical argument and calculations are more interesting than his somewhat difficult experimental arrangement.

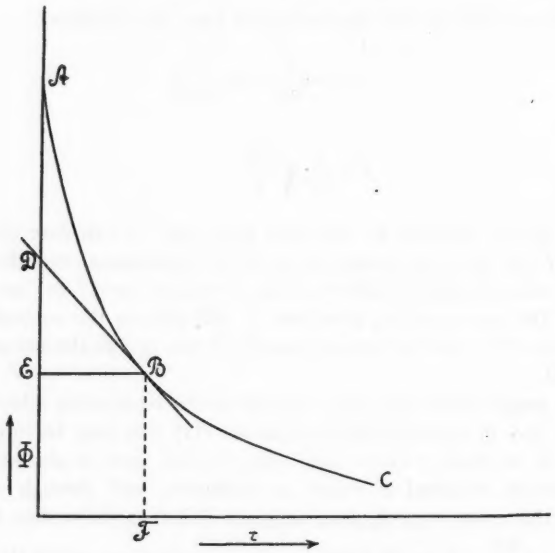


FIG. 4. DIAGRAM OF GRAPHICAL SOLUTION

They have been discussed in another connection. While in general they are correct, they involve some errors which depend on the distribution but seem to have been less than his experimental errors and to have escaped observation. Schloesing also added evidence to show that the sedimentation results were independent of the absolute weight and absolute concentration of the soil suspension between certain critical limits. This was confirmed by the writer (16, 18) and by Wiegner (40).

A *statistical* method was further used by The Svedberg and K. Estrup (36) who with the aid of a microscope counted particles such as gamboge, cocoa-milk and mercury, of different settling velocities, and so obtained curves representing the relative number of the particles as a function of their size.

An improvement along these lines is due to A. Westgren (39). The suspended particles are collected in a rectangular microscope chamber and accumulated by centrifugation along a pizeïne-edge of the chamber. The preparation is then turned 180° from the original position and placed in a microscope with the edge upward. While the particles fall from the horizontal plane they separate because of their various weights in strata of approximatively the

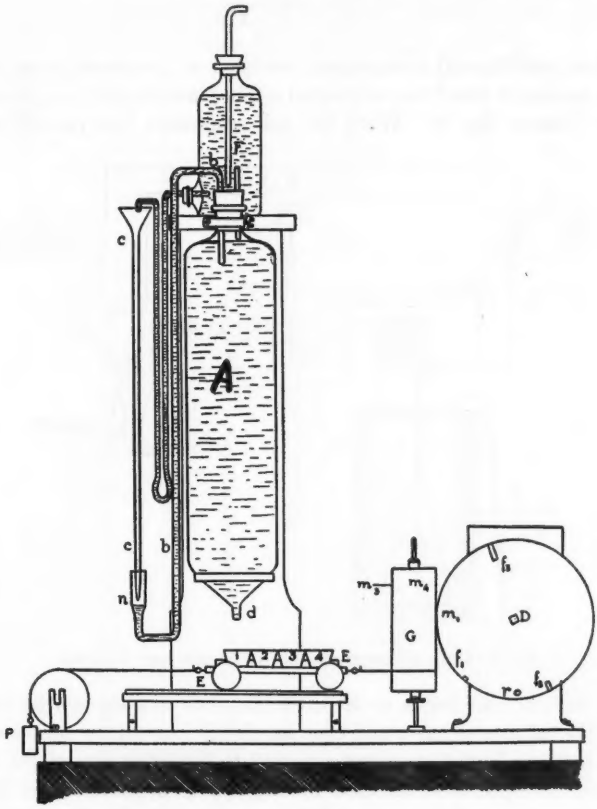


FIG. 5. SCHLOESING'S EXPERIMENTAL ARRANGEMENT

the same size. By then turning the preparation sidewise through an angle of 90°, they are sedimented toward the other perpendicular pizeïne-edge of the chamber. With the aid of Einstein's formula for the gravity distribution of the particles in a homogeneous disperse system, information is obtained on the size of the particles occurring in the sample, as well as of their relative numbers.

The immense labor of "counting" soil particles and the impossibility of adjusting the previous methods to soil samples led me in 1914 to the first investigation of distribution curves of soil particles and a new experimental method to obtain the same was devised (16) based on equation (17) where V was replaced by $\frac{1}{2}r$ F (r) so that:

$$F(r) = -\frac{2t^2}{r} \cdot \frac{\frac{d^2A}{dt^2}}{A_\infty} \tag{22}$$

The first experimental arrangement consisted of a sedimentation cylinder, near the bottom of which was suspended a thin plate attached to one arm of a sensitive balance (fig. 6). When the soil suspension was poured into the

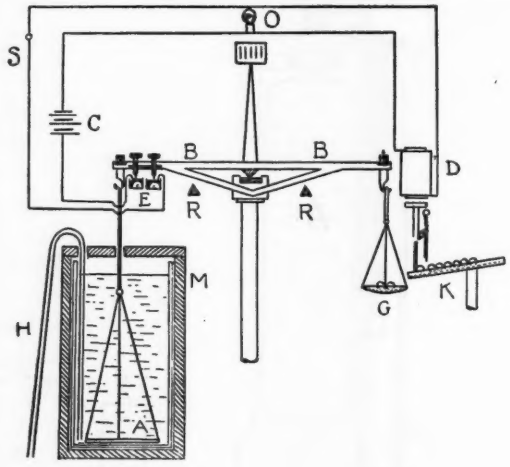


FIG. 6. ODÉN'S SEDIMENTATION CYLINDER AND BALANCE

cylinder the particles began to settle on the plate and the weight increased, causing the balance to move and close an electric current, by means of which a small ball was loaded on a pan attached to the other arm of the balance. The times for equal small increases in weight were determined and from this "accumulation curve" the second differential was graphically obtained and $F(r)$ calculated according to equation (22); or the direct graphical method was employed by means of which differences in $F(r)$ could be obtained for distinct intervals of r. The successive improvements of this instrument are visible from figures 7 and 8, and plate 1 and are described in the original papers (16, 18, 23, 24). Similar arrangements were employed by H. Green (9) and by K. Sundberg (35). The method proved to be useful for the study of the formation of precipitates and colloids (20), as well as for geological questions (23), (24).

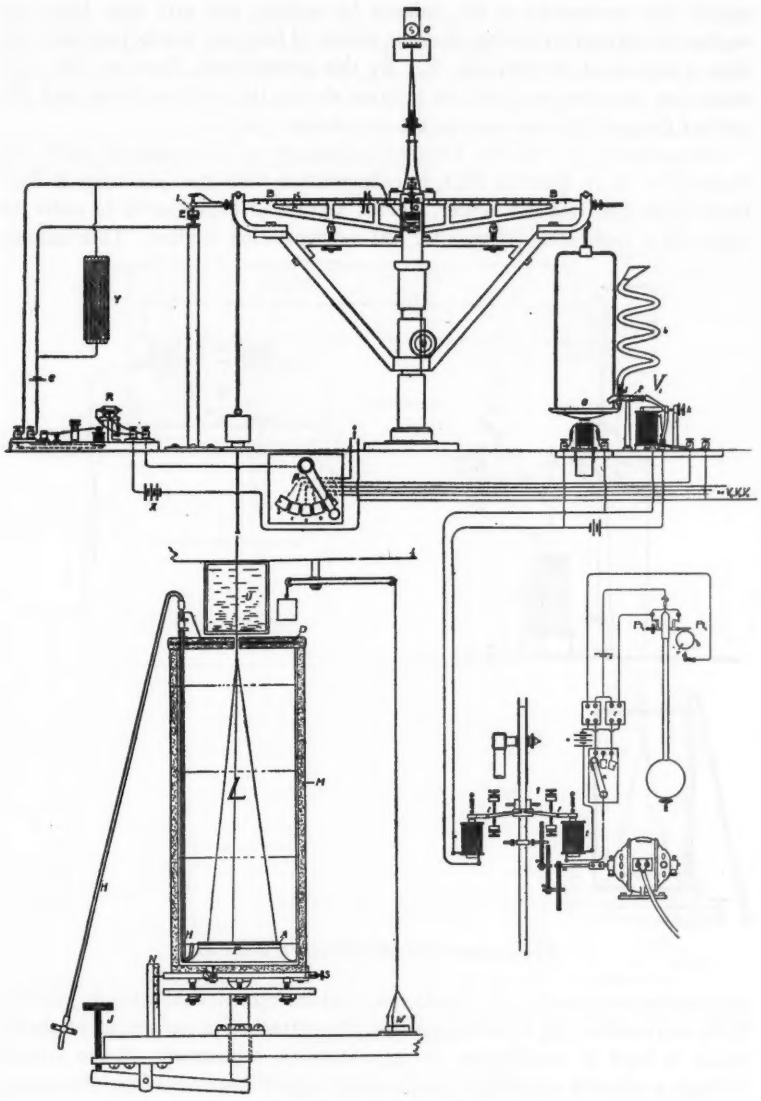


FIG. 7. APPARATUS USED BY ODÉN

The importance of size-frequency curves in colloid chemistry led Svedberg and Rinde (38) to improve the sensitivity of the balance and introduce electrical control of the weighing, and Harlan W. Johnson (11) found a way to

register the movement of the balance by making one arm very long and register its way on a rotating drum by means of frequent sparks jumping over from a pointer at the end (fig. 9). By this arrangement, however, the sedimentation pan does not hold its position during the sedimentation, and the path of the particles increases as the experiment goes on.

Independently of this the Physical Laboratory at Rothamsted under the head of Dr. B. A. Keen in 1921, in collaboration with the Cambridge & Paul Instrument Co. and the writer, started a series of experiments in order to construct a registering balance for soil sedimentation studies. This balance

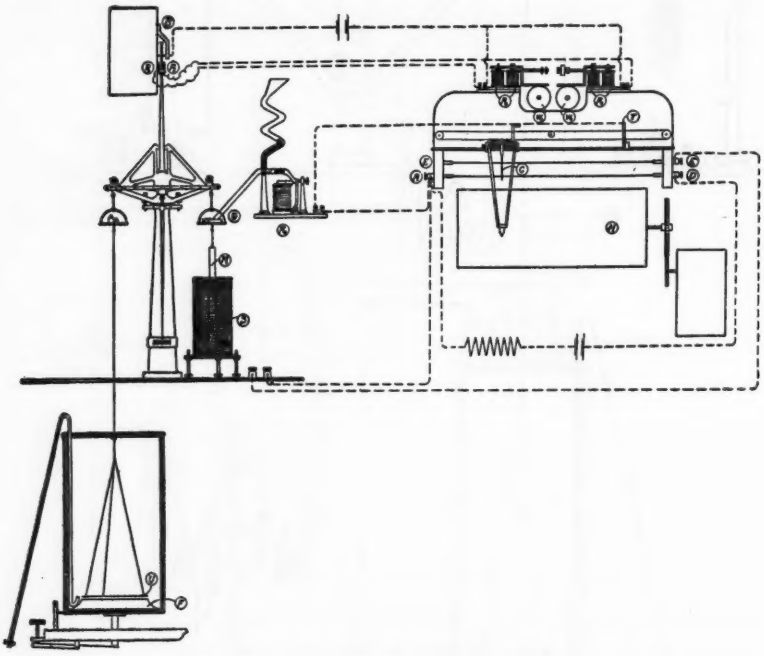
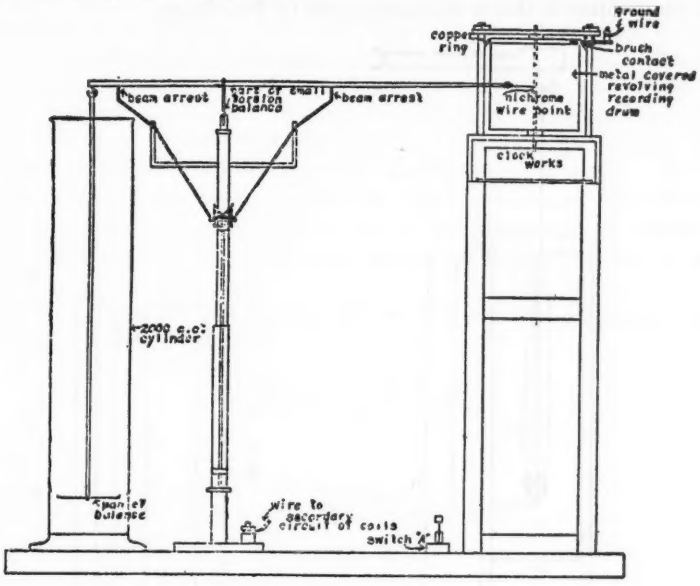


FIG. 8. IMPROVED ODÉN-KEEN'S BALANCE

was first demonstrated at the London physical-instrument exhibition in January, 1923, and consists (fig. 8) of a suspended plate attached to one arm of a balance, which is kept in equilibrium by an automatic adjustment of the current through a solenoid attracting a permament magnet suspended from the second arm of the balance. When the weight of the sediment reaches a given amount, i.e., when the solenoid current reaches a given value, a small metal sphere is automatically placed on the second pan of the balance, and the solenoid current returns to a smaller value. The strength of the current is recorded on a moving paper band, and the operation just described results in this curve representing

a series of steps. A very open and sensitive scale can therefore be used for the curve, although the actual trace is confined within narrow limits of width. The sensitivity of the record can be reduced or increased by suitable adjustments of the component parts of the instrument. The periodic replacement of the electromagnetic attraction by the metal balls results in the sensitivity in any given experiment remaining constant.



WIRING DIAGRAM OF BALANCE.

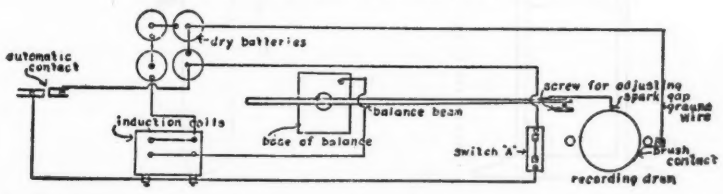


FIG. 9. JOHNSON'S AUTOMATIC RECORDING BALANCE ARRANGED FOR MAKING MECHANICAL ANALYSES OF SOILS

(From Soil Science, vol. 16, p. 365)

The next attempt along another line to obtain the distribution is due to U. Pratolongo (28) 1917. It could be based on equation (15), and simply consists in determining "the density," by means of a Westphal's balance (fig. 10), in the top layer of the soil suspensions as a function of time. Curves for the variation of the density with time are given, the author stating "e

dalla tavola dei tempi e delle densita riesce facile desumere la curva di distribuzione dei costituenti del terreno di diversa finezza." And again: "Un calcolo assai semplice, che puo essere anche notevolmente abbreviato con l'impiego di methodi grafici, conduce direttamente alla conoscenza della distribuzione dei costituenti del terreno in funzione della loro diversa finezza."

But no attempt to draw the distribution-curves for the samples investigated is found either in this or following papers by Pratolongo.

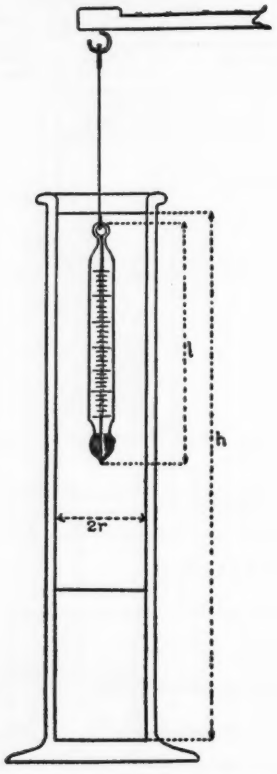


FIG. 10. ARRANGEMENT USED BY PRATOLONGO

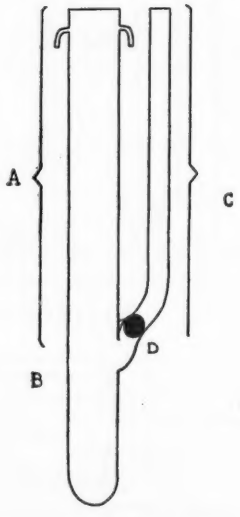


FIG. 11. DIAGRAM OF WIEGNER'S APPARATUS

According to my experiences the main difficulty with a method like this lies in the accumulation of small deposits of clay at the top of the densimeter, the weights of which have to be subtracted from the readings of the specific gravity. If the upper area exposed to such accumulation is known, this of course may be taken into account, but it makes the calculations heavy and tedious.

The Schurecht method (32) used at the United States Bureau of Mines, Columbus, Ohio, differs from Pratalongo's method only with regard to the form of the immersed plummet. The percentage of clay in suspension above the plummet is recorded as a function of log (time), and characteristic curves were obtained for various clays, but no attempt to get the distribution function is made.

A third and quite independent way of attacking the problems in question was opened by G. Wiegner, 1917, and consists in the determination of the variation in pressure of a soil suspension with time (40). The arrangement, which is very simple, is illustrated in figure 11. In the big "sedimentation tube" A the soil suspension is poured while the stopper D is closed and the "measuring tube" C filled with pure water. After thorough shaking, the instrument is suspended on the spurs and the glass stopper is opened. As the specific gravity of the suspension is greater than that of water, the meniscus in the measuring tube is higher than that of the suspension, the difference being proportional to the pressure and the bulk of soil particles above the level D.

Wiegner has not used the formula (14) but calculated the percentage fraction x which passes the level D:

$$x = \frac{100\, W_1\, (1 - V_1)\ (S_B\, V - S_W)}{W\, (1 - V)\ (S_B \cdot V_1 - S_W)} \qquad (23)$$

where

V_1 = the ratio between the heights of the liquids in the tubes
V = the same ratio at starting time
W_1 = the amount of water in "sedimentation tube"
W = the same at the beginning
S_w = specific gravity of water
S_b = specific gravity of soil particles

x as variable with respect to time is here the same as A in our equation (17) and Wiegner makes use of the same graphical method to obtain certain "size groups" as developed by the present writer.

Wiegner's method, with the collaboration of H. Gessner, has been improved and the difference between the menisci photographed and recorded on a rotating drum (8) (fig. 12).

The great advantage of Wiegner's method is its simplicity and the cheapness of the instrument; its weak point is that the measured variable is only some few centimeters and consequently the accuracy is not very great. Furthermore, small variations in temperature, e.g., the radiation from the body of the experimenter, may raise the temperature in the "measuring tube," thereby decreasing the specific gravity and causing considerable error.

A small variation was introduced by Wo. Ostwald (27), who placed the stopper at the top instead at the bottom of the "Measuring tube" (now called

"Vergleichsrohr") (fig. 13). Wo. Ostwald has also invented another instrument called "Einschenkel-flockungsmesser," as shown in figure 14. The suspension is poured into the bowl S and the bulb E evacuated to a certain pressure P the value of which is ascertained in a previous "test experiment." If by means of the "threeway stopper" the bulb is put into communication with the tube, dipping down into the bowl with the suspension, the latter is pressed up to a certain height X by the atmospheric pressure B. If now some particles are settling below the surface of the liquid outside the tube, and

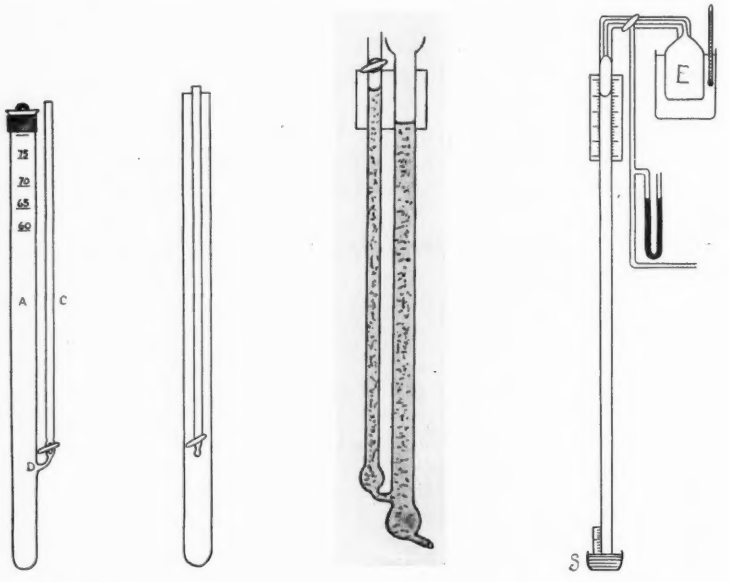


FIG. 12 FIG. 13 FIG. 14

FIG. 12. WIEGNER AND GESSNER'S IMPROVED APPARATUS
FIG. 13. VARIATION OF WIEGNER'S APPARATUS INTRODUCED BY OSTWALD
FIG. 14. OSTWALD'S "EINSCHENKEL FLOCKUNGSMESSER"

$(B\text{-}P)$ is maintained constant, the height of the suspension in the tube will increase as the particles disappear from the suspension in the tube. The principle for measuring the distribution may be most simply interpreted as follows:

If A_1 is the quantity of particles which at a given time have passed below the surface, and X_1 is the height of the column at this time then $\frac{A_1}{A_\infty}$ will be the fraction which has passed and $1 - \frac{A_1}{A_\infty}$ the fraction which remains in the tube, or $(A_\infty - A_1)$ the amount remaining in the tube. If A_2 is the same

amount at a later time, t_2 and X_2 the corresponding value for the height difference between the surfaces, we have at t_1

$$B_1 - P = X_1 + (A_\infty - A_1) \tag{24a}$$

at t_2

$$B_2 - P = X_2 + (A_\infty - A_2) \tag{24b}$$

and assuming the atmospheric pressure constant $B_1 = B_2$ we have

$$X_2 - X_1 = A_2 - A_1 \; ; \; dx = dA$$

$$\frac{dx}{dt} = \frac{dA}{dt} \; ; \; \frac{d^2x}{dt^2} = \frac{d^2A}{dt^2} \tag{25}$$

and we may use equation (17) to calculate Y.

No attempt to obtain the distribution has yet been made by Wo. Ostwald, but graphical results of the settling velocity were obtained by empirical and graphical methods, and the instrument seems to be useful for a more detailed study of coagulation and aggregation phenomena. The main errors seem to arise from inevitable variations in the atmospheric pressure if the experiments are extended over any longer period, and from variations in temperature affecting the pressure in E. A further development of the Wiegner-method was recently made by F. Zunker (41) who obtained more accuracy in the measurement of the height difference by connecting the top and bottom layers to manometers kept apart from the instrument thus avoiding frequently occurring errors caused by the formation of foam at the top of suspensions which have been shaken violently (fig. 15). Zunker also developed several new methods for the calculation of the relative (specific) and absolute surface of the soil particles, and showed that the interpretation of this conception (specific surface) was very useful for practical irrigation problems.

The chief difficulties with Wiegner's apparatus, according to my experiences, are the *small* variation in height between the suspension and the measuring-tube, the sensitivity of the latter to variations in temperature, and the expansion and contraction caused thereby, thus introducing uncontrolled errors in the measurements. Furthermore, the instrument is fragile and the shaking up of the suspension may be rather difficult.

In order to increase the difference in height I have introduced pentane or some other liquid of low specific weight in the measuring-tube and in order to avoid temperature differences between the suspension and the measuring liquid, I have immersed the measuring tube (manometer) in the suspension and made special arrangements for filling and the stirring of the suspension before the actual sedimentation measurement takes place.

The instrument which has been most satisfactory and proved useful in our laboratory is shown in figure 16, and photographs of some of our sedimentation-instruments are given in plate 2.

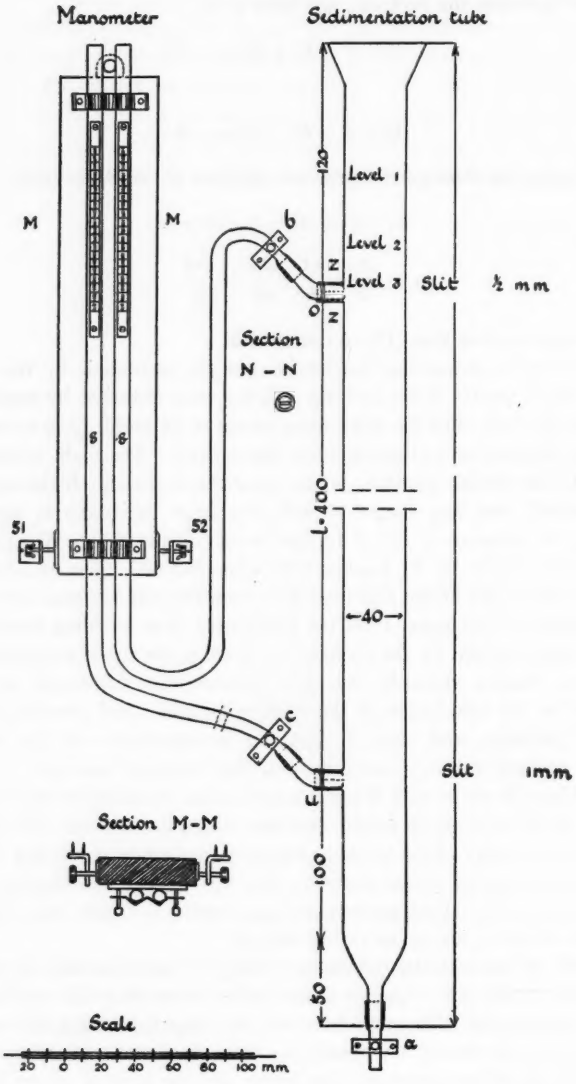


FIG. 15. ZUNKER'S APPARATUS

The wide glass tube *U* (7 cm.) is fitted at its lower end into the funnel-shaped metal case *M*, which is big enough to take up all the sedimenting particles and is at the bottom provided with a tap *N* for inlet and outlet of the suspension which may be effectuated from the supply vessel *S* by means of compressed air *P*.

The upper part of the glass tube is by some sort of bayonet joint tightly closed by the lid *R*, provided with a large edge rising several centimeters and through which is inverted the manometer *AC*, also provided with a stopcock *B*. The lid is also furnished with an outlet tube *T* with stopcock, thus letting out the overflow of liquid when the system is filled with the suspension, and finally a narrow channel closed by a tap *L* and connecting the receptacle with the sedimentation tube and a pointer *W*, indicating the height of the water. The manometer consists of a not too narrow glass tube *A*, etched with a millimeter scale and widened to a bulb *C* at the lower part. This bulb is provided with a small hole *D*, thus giving communication between the two liquids: the suspension outside and the manometer fluid inside the bulb. It is convenient, however, not to have the bulb completely filled with the light fluid but to have some water up to a few millimeters height at the bottom, in order to prevent bubbles of pentane from rising through the suspension during the experiment. The whole arrangement forms a kind of "communicating tubes system." Now as the particles of the suspension sink below the level *D*, the pressure decreases and the meniscus of the manometer sinks. This causes some water to leave the bulb at the bottom, but this quantity is very insignificant since the whole displacement of fluid in the manometer-tube is only about 0.2 cc. The reason for having a narrow manometer tube and bulb at the end of it is to allow a great vertical displacement of the meniscus at *H* as the pressure above *D* decreases without any considerable displacement of the surface of separation of the two liquids at *D*.

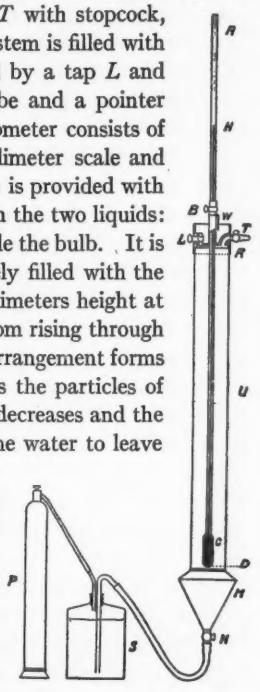


FIG. 16. ODÉN'S PRESSURE-TUBE INSTRUMENT

The sedimentation analysis is now carried out as follows: The lid with its manometer is removed and filled by sucking at *A* first with the special manometer fluid (pentane) and then with a few drops of the water at the bottom. Any air bubbles are cleared away while the bulb is still immersed in water and the stopcock *B* is closed.

Meanwhile, so much water is poured into the funnel that the lower part of the bulb is just immersed into the water and no air-bubbles are allowed to enter the manometer system *ABCD*, and then the lid is adjusted and fastened on the top of the sedimentation tube.

Now the instrument is ready for use. The supply bottle is shaken violently and a pressure of 1 atmosphere put on while L is closed. The tap N is at first opened, and immediately afterward T, which allows the suspension to enter the tube rapidly, pushing the air through T. As soon as the suspension has filled the sedimentation tube and the fluid goes out at T, the tap N is closed and the supply bottle disconnected. After the tap T has been closed the tap L and the manometer tap at B are cautiously opened, whereupon the meniscus sinks at H. During the first minute there is generally some jumping up and down of the meniscus indicating currents and disturbances in the system. Then we have to adjust the water-level at W by pouring in or removing some water so that the relative level of the suspension in all experiments is the same. After the lapse of a minute we generally find a continuous sinking of the meniscus which has to be recorded as a function of the time, calculated from the moment the tap N is closed. These readings give the "height-difference curve" or "pressure-curve" previously referred to.

The variation of specific gravity may evidently be measured by taking out samples of definite volume and determining the dry matter thereof, M; then dM is evidently equal to $d\varphi$ and equations (10) and (11) may be used to calculate the distribution. G. W. Robinson's new method (29) is of this kind and simply consists of taking out 20 cc. with a pipette at different times and determining the dry matter (fig. 17). Robinson has not tried to get the distribution-function but determined the ordinates of what he calls "the summation curve" as functions of $log\ v$, that is the Z-function in the present paper. Robinson's method seems to be a distinct advance compared with the old mechanical analysis, with regard to both simplicity and accuracy. Its chief drawback seems (to me) to be the inevitable errors in taking the samples which from Robinson's figures seem to amount to several per cent in the single m value, and are therefore capable of causing large errors if the material is of somewhat irregular distribution (Robinson, p. 318). It is possible that these errors could be reduced by following the technique recommended by D. S. Jennings, M. D. Thomas and W. Gardner (10) the essential point of which is a "multiple-mouthed pipette" (fig. 18), through which small volumes (2 cc.) could be sampled off with great accuracy. Like Robinson, they recommended nephelometric methods for the estimation of the quantity of particles, but since the intensity of the scattered light will vary not only with the concentration but also with the size of the particles, it seems doubtful if this would be of much value. Similar in the essential features, but adapted for serial operation, is G. Krauss method demonstrated at the Third International Soil Congress at Prague in 1922, but not published until recently (13).

Finally, it may be recorded that an experimental arrangement seeking to make use of equation (13) and to determine $\frac{d^2\pi}{dx^2}$ at distinct times, was tested in the writer's laboratory in the autumn of 1922. A big sedimentation tube, 1.8 meters high and 5 cm. wide, was connected with capillary tubes filled with

pentane acting as manometers (fig. 19). The suspension was poured into the Woulff-flask *B* and pressed into the sedimentation tube, while the "manometers" were cut off by means of spring clips. After a definite time the clips were opened and the pressures read off on the scale *E*. From this a curve was drawn and $\frac{d^2\pi}{dx^2}$ graphically obtained. The experimental difficulties and errors proved to be very great, however, mainly on account of variations in temperature between different parts of the necessarily large instrument, heat radiations

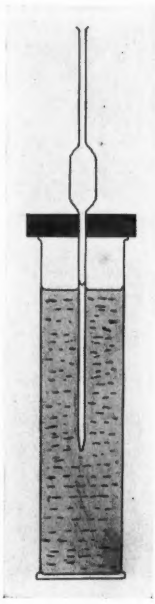


FIG. 17. DIAGRAM ILLUSTRATING ROBINSON'S METHOD

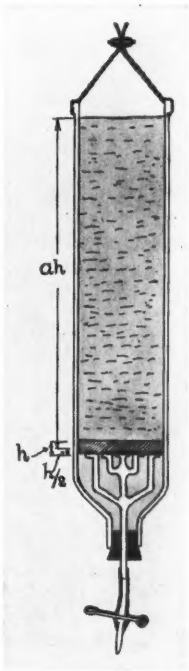


FIG. 18. THE "MULTIPLE-MOUTHED PIPETTE" OF JENNINGS, THOMAS AND GARDNER

from the body of the observer causing volume increase in the pentane tubes during reading off, and the method was abandoned.

The experimental applicability of equation (10) has been suggested in the writer's laboratory by means of a "differential densimeter" consisting of two spheres of equal size balanced against each other at a constant distance dx, but the success was not sufficient to justify its use. Evidently, determinations of the amount of solid matter at increasing depth makes equation (10) applicable. Series of such measurements have been carried out on soils by A. N. Puri at the

Rothamsted Laboratory under B. A. Keen's supervision, and also tested in my laboratory with promising results. In the clever hands of The. Svedberg this principle has been successfully applied to other colloids; Svedberg and Rinde (38) determined the variation in amount of colloidal gold with depth after 1040 minutes centrifugation by means of optical methods and were able to draw the distribution curve for the gold suspension by a graphical method.

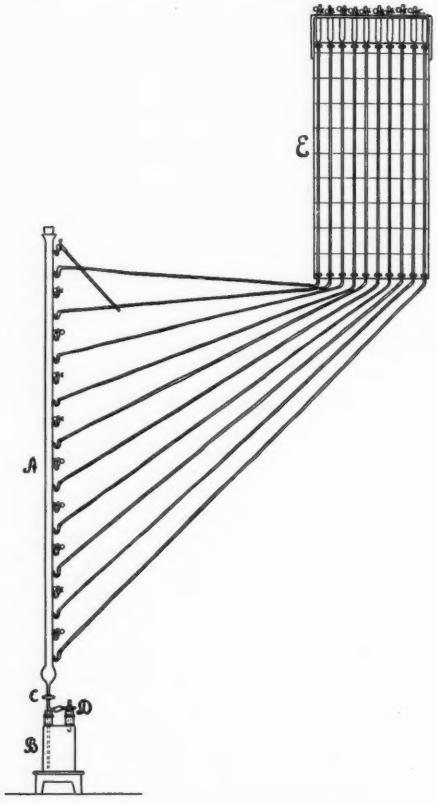


FIG. 19. APPARATUS USED IN CONNECTION WITH EQUATION (13)

These centrifugal experiments have been continued by Svedberg and J. B. Nichols (37).

Though it is evidently too early to give any definite judgment of the advantages and disadvantages of the methods here referred to it is the writer's opinion that the practical range of size for which Wiegner's instrument or modifications thereof may be used is from 100 to 5 μ, while the automatic balance is recommended in the interval from 10 μ to 0.1 μ.

In a later paper some results and applications of the methods for the study of the physical properties of soils and sediments will be given.

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PLATE 1

ODÉN'S FIRST MODEL OF SEDIMENTATION APPARATUS

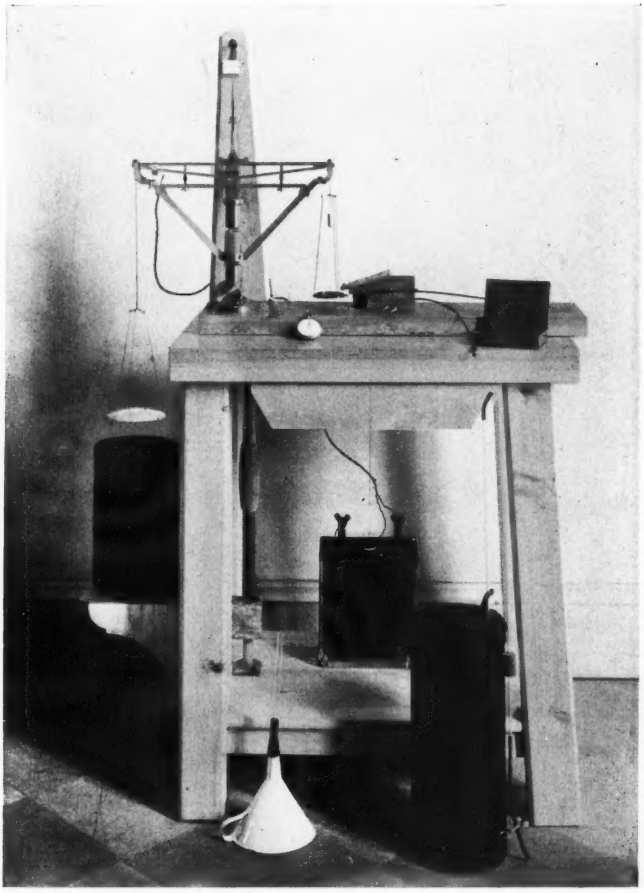
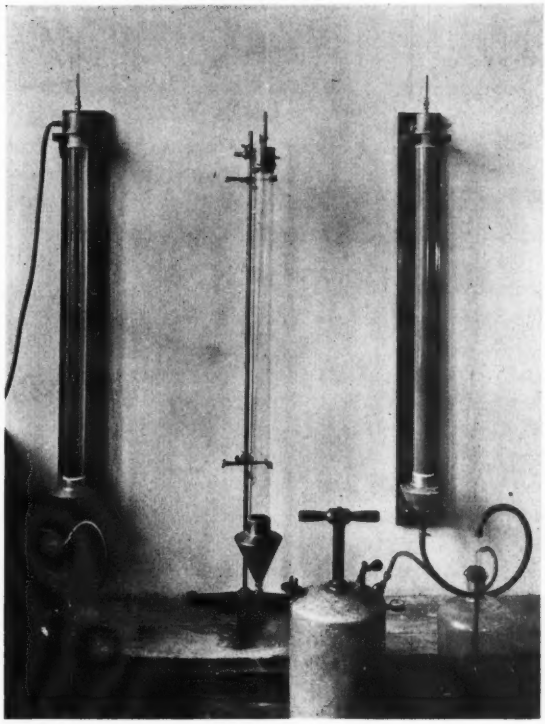


PLATE 2

ODÉN'S PRESSURE-TUBE INSTRUMENTS



REVIEWS OF WORKS ON SOIL PUBLISHED IN ITALY, SPAIN AND PORTUGAL DURING 1923[1]

BRUGUES, CASIMIRO. 1923 *Agrology; Colloidal Clay.* (De Agrologia; la arcilla coloide.) *In* Boletin della Real Academia des ciencias y artes de Barcelona Tercera Epoca., v. 4, no. 7.

On March 3, 1922, the author read before the Academy a paper which deals with a general study of colloids and especially of *dispersions* (particularly of the quantitative aspect of dispersoids). The paper also has to do with the colloids of agricultural soil, the structure of clay and its properties as a colloid. He sets forth, then, the proposed methods for the determination of the colloids of the soil, especially the hygroscopic and colorimetric methods, giving special attention to the question of the true value of these methods.

DE FIESTOIS, R. 1923 *The origin of sodium nitrate.* (El origen del salitro.) Revista de la Real Academia de Ciencias exactas fisicas y naturales de Madrid, v. 20, s. 2, no. 5, Madrid.

The author, who is connected with the factory "Carmela" of Santiago (Chile), after having reviewed the principal theories on the origin of the enormous deposits of sodium nitrate and having discarded all these theories, maintains that one must abandon the idea of the inactivity of air nitrate and admit that the origin of the nitrate of soda is due to the fact that, in the early epochs of the world, the eruptive rocks were energetically attacked by a rain of acids which disintegrated the superficial layers, leaving only the insoluble materials. Of the salts which were formed at the same time, the soluble ones penetrated the soil and the insoluble ones remained on the surface.

This theory could explain the composition of the minerals of the region as well as the important differences in the structure of the layers. Also the study of the deposits of nitrates in California would justify this view.

DE CAPITANI DA VIMERCATE, SERAFINO 1923 *The meteoric conditions of soil and of cultivation in relation to irrigation.* (Le condizoni meteoriche di suolo e di coltura in rapporto all'irrigazione.) *In* Le stazione agrarie sperimentali. v. 56, no. 1, 3.

This work which has only indirect connections with soil science, distinguishes the four following types of irrigation:

1. Irrigation with a view to completing the moisture of the soil;

[1] These abstracts were prepared by G. Rossi, Royal Agricultural High School in Portici, Naples, Italy, and translated by René Jules Dubos, New Jersey Agricultural Experiment Stations.

2. Irrigation for the correction of soil temperature;
3. Irrigation for the improvement of soil fertility;
4. Irrigation for the cultivation of aquatic plants.

On the basis of numerous theoretical and experimental data, the author concludes that, by means of adequate corrections of the physical, chemical and biological factors, it is possible to reduce the quantity of water required for irrigation or even to cultivate without irrigation (by means of dry farming) crops which would otherwise require an intensive irrigation.

CORRADO, LUMIA 1923 *The accellerating effect of amides on the denitrifying processes in the soil.* (Le amidi accelerano l processi di denitrificazione nel terreno.) *In* Annali di Chimica Applicata, Ann. 7, v. 13, no. 3.

The author states by way of introduction, that the numerous denitrifying microörganisms have been divided into two groups which were termed by Weyssember as "false" and "true" and by Grimbert and Bragos as "direct" and "indirect" denitrifiers. The false and indirect denitrifiers are limited to reducing the nitrates to nitrites, but they are capable also of evolving free nitrogen, if there is present in the cultural medium an amide which would react with the nitrous acid formed. Hence, the action of the indirect denitrifiers, that is the evolution of free nitrogen, is identical in the end with that of the direct ones only when an amide is present in the culture medium. It is, however, to be noted that the nitrogen evolved by the indirect dentrifier is the sum of both that contained in the nitrates (previously transformed into nitrites) and that contained in the amides. The relation between the two volumes of nitrogen varies according to the constitution of the amides used.

The author has used asparagin as an amide for soil inoculation in order to have an association of the various denitrifiers, which is precisely the condition in an agricultural soil. As a nutritive solution he has used the following (not very different from that of Giltay): 100 gm. distilled water, 10 gm. potassium nitrate, 7 gm. citric acid, 2 gm. magnesium sulphate, 2 gm. dibasic potassium phosphate, 0.2 gm. calcium chloride, and 0.5 gm. ferrous sulphate.

From his experiments he derives the following conclusions:

1. The amides, completing the action of indirect denitrifiers, accelerate and make possible the complete decomposition of the nitrates contained in the medium at a *rather low temperature.*

2. From the effect of the varying influence of the temperature on the course of development of the individual bacterial species, and because of the different chemical work which the two groups of denitrifiers accomplish, it is demonstrated that the indirect denitrifiers, when associated with direct ones, exercise a greater activity than the latter, especially at low and medium temperatures. This difference in activity diminishes with increase of temperature, and it is almost nil around 35°–37°C., which temperature seems to be best for the direct denitrifiers.

The author derives from these conclusions some practical applications concerning the use of fertilizers and manures.

MARCILLA, JUAN 1923 *The Hungarian method for the determination of the nature of the lime in the soil.* (El metodo llamado hungaro para la apreciacion de la naturaleza de la caliza de las tierras.) *In* Boletin de Agricultura tecnica y economica. (Organo oficial de la Direction general de Agricultura y Montes.) Madrid, June 30, 1923, Ann. 15, no. 174.

The author states that this method, which has been devised for studying the quantity of lime contained in soils in relation to the chlorosis of American grape vines and which consists in determining not all the lime but only the active lime (Hungarian grade) cannot be considered as a rigorous method of analysis. However, it can give very useful information as to the property of soils to determine chlorosis.

FERRARA, A., AND TITTA, G. 1923 *Investigations of a sample of water from Uadi Gattarg River, Cyrenaica.* (Ricerche su di un campione di "torbida" dell Uadi Gattarg, Cyrenaica.) *In* L'Agricoltura Coloniale, Ann. 17, no. 6, Rome.

Analyses designed for determining the quality of the water of the river in consideration for irrigation purposes. The content of soluble substances (0.82 per cent) and of chlorine (0.15 per cent) makes this water valuable for irrigation.

SCURTI, F. 1923 *For the knowledge of agricultural soil; natural zeolites.* (Per la conoscenza del terreno agrario. Le zeoliti naturali.) *In* Annali di Chimica Applicata, Ann. 7, v. 13, no. 4.

It is known that the principal typical zeolites are: (1) Natrolite, (2) Scolecite, (3) Levynite, (4) Wellsite, (5) Mesolite, (6) Phillipsite, (7) Edingtonite, (8) Cabazite, (9) Laumontite, (10) Gmelinite, (11) Offretite, (12) Fauyasite, (13) Harmotome, (14) Heulandite, (15) Desmine, (16) Epistilbite, (17) Erionite, (18) Brewsterite, (19) Stellerite, (20) Pseudonatrolite, (21) Flokite, (22) Ptilotite, (23) Mordernite.

On the other hand, it is known that in regard to the structure of the zeolites, the following fundamental points may be stated:

a. That the zeolites are products of transformation of the feldspars and feldspatoids—that is, of the dimeta-orthosilicates.

b. That the zeolites are double silicates of aluminum and alkali or alkali earth metals in which the aluminum is present in hydrated form. The possible groups under consideration are $Al \begin{matrix} - \\ - \end{matrix} \begin{matrix} OH \\ OH \end{matrix}$ monovalent and Al — OH bivalent.

c. That the water which the zeolites give out by heating comes from the hydroxyls. These are partly combined with silicon and partly with aluminum and are eliminated, leaving an atom of oxygen for every pair and forming one molecule of water.

d. That, for the same silicon aluminum derivative, the alkali or alkali earth metal may be combined (always through oxygen) with the silicon or the

aluminum. Two forms of the same zeolite are so obtained, the metal of which is endowed with different mobility.

e. That between the silicon, the alumium and the basic compound exist definite relations which are the following for the typical natural zeolites known up to the present time:

1. $3\ Si\ O_2;\ Al_2\ O_3;\ R_2O$
2. $4\ Si\ O_2;\ Al_2\ O_3;\ R_2O$
3. $5\ Si\ O_2;\ Al_2\ O_3;\ R_2O$
4. $6\ Si\ O_2;\ Al_2\ O_3;\ R_2O$
5. $7\ Si\ O_2;\ Al_2\ O_3;\ R_2O$
6. $9\ Si\ O_2;\ Al_2\ O_3;\ R_2O$
7. $10\ Si\ O_2;\ Al_2\ O_3;\ R_2O$

R_2 may represent one atom of bivalent metal or two atoms of monovalent metal.

On the basis of this data, the author has tried to elucidate the structure of the natural zeolites. Since the relations between the silicon, the aluminum and the base give the impression that the compounds constitute a homologous series of silico aluminates, he has expressed this series in connection with the series of alkali and alkali earth salts of silico-aluminic acids. For these salts, he has calculated the corresponding percentages of silicon, aluminum, water and base. Utilizing the vast analytical material in existence, he has referred the percentages found for the silicon, the aluminum and the bases to the quantity of theoretical water and has compared the figures thus obtained with the figures required by the theory. The series of the silico-aluminic acids would be the following:

Dimeta-orthosilica aluminic acid.
Dimeta-diorthosilica aluminic acid.
Dimeta-triorthosilica aluminic acid.
Dimeta-tetraorthosilica aluminic acid.
Dimeta-pentaorthosilica aluminic acid.
Dimeta-hexaorthosilica aluminic acid.
Dimeta-heptaorthosilica aluminic acid.
Dimeta-octoorthosilica aluminic acid.

As is seen, the series in question is that of the dimeta-n-orthosilica aluminic acids and each term differs from the inferior and superior by one $H_2\ Si\ O_3$

According to this concept, the natural zeolites are simply calcium, sodium, potassium, barium and strontium salts of the dimeta-n-orthosilica aluminic acid.

The water which some of them contain in excess of the theoretical water may be regarded as the absorption water corresponding to Van Bemmelen, Sommerfeld and Zambonini ideas; this appears natural if we consider that zeolites are silico-aluminic hydrates and stand between crystalloids and colloids.

By comparing the experimental and theoretical figures, the author has obtained the following values:

1. Natrolite $Si_3\ O_{12}\ Al_2\ H_4\ Na_2$

Dimeta silicate of sodium and of aluminum. Calculated molecular weight 380.9.

2. Scolecite $Si_3\ O_{12}\ Al_2\ H_4\ Ca$

Dimeta orthosilicate of calcium and of aluminum. Molecular weight 374.9.

3. Levynite $Si_3 O_{12} Al_2 H_4 Ca$

Dimeta orthosilicate of calcium and aluminum. Molecular weight 374.9.

4. Wellsite $Si_3 O_{12} Al_2 H_4 Ca$

Dimeta orthosilicate of calcium and of aluminum in which, however, a good part of the calcium is replaced by barium, strontium, magnesium, potassium and sodium.

5. Mesolite $Si_3 H_2 Al H_4 Ca$

Dimeta orthosilicate of calcium and of aluminum in which the calcium is largely replaced by sodium. Calculated molecular weight 374.9.

6. Edingtonite $Si_3 H_2 Al H_4 Ba$

Dimeta orthosilicate of barium and of aluminum. Calculated molecular weight 472.2.

7. Phillipsite $Si_3 O_{12} Al_2 Ca$

Dimeta orthosilicate of calcium and of aluminum in which the calcium is partially replaced by sodium, potassium, barium and magnesium and the aluminum sometimes by small quantities of iron. Calculated molecular weight 374.9.

8. Chabazite $Si_4 O_{15} H_6 Na_2$

Dimeta-silicate acid of sodium and of aluminum. Molecular weight 459.2.

9. Laumontite $Si_4 O_{15} Al_2 H_8 Ca$

Dimeta-orthosilicate acid of calcium and of aluminum. Calculated molecular weight 453.2.

10. Gmelinite $Si_4 O_{15} Al_2 H_8 Ca$

Dimeta-diorthosilicate acid of calcium and of aluminum in which the calcium is in good part replaced by sodium. Molecular weight 453.2.

11. Offretite $Si_4 O_{15} Al_2 H_7 K$

Dimeta-diorthosilicate acid of aluminum and of potassium in which a part of the potassium is replaced often by calcium. Molecular weight 453.2.

12. Faujasite $Si_5 O_{18} Al_2 H_8 Ca$

Dimeta-triorthosilicate acid of calcium and of aluminum in which a part of the calcium is replaced by sodium. Molecular weight 531.5.

13. Harmotome $Si_5 O_{18} Al_2 H_8 Ba$

Dimeta-diorthosilicate acid of barium and of aluminum in which the small quantities of barium are often replaced by sodium and potassium. Molecular weight 628.8.

14. Heulandite $Si_6 O_{21} Al_2 H_{10} Ca$

Dimeta tetraorthosilicate of calcium and of aluminum in which a part of the calcium is often replaced by the sodium and sometimes also by the strontium, a base which in the zeolites is rather rare. Molecular weight 609.9.

15. Desmine $Si_6 O_{21} Al_2 H_{10} Ca$

Dimeta-tetraorthosilicate acid of calcium and of aluminum in which the calcium may be in small part replaced by the sodium and by the potassium. Molecular weight 609.8.

16. Epistilbite $Si_6 O_{21} Al_2 H_{10} Ca$

Dimeta-tetraorthosilicate acid of calcium and of aluminum in which a small part of the calcium is replaced by the sodium. Molecular weight 609.9.

17. Erionite $Si_6 O_{21} H_{10} Ca$

Dimeta-tetraorthosilicate acid of calcium and of aluminum in which the calcium is partially replaced by the sodium and by the potassium. Molecular weight 609.8.

18. Brewsterite $Si_6 O_{21} Al_2 H_{10} Sr$

Dimeta tetraorthosilicate of strontium and of aluminum in which a part of the strontium is replaced by the barium and by the calcium. Molecular weight 657.1.

19. Stellerite $Si_7 O_{24} H_{12} Ca$

Dimeta-pentaorthosilicate acid of calcium. Molecular weight 688.1.

20. Pseudonatrolite $Si_7 O_{24} Al_2 H_{12} Ca$

Dimeta-pentaorthosilicate acid of aluminum and of calcium. Molecular weight 766.4.

21. Flokite $Si_9 O_{30} Al_2 H_{16} Ca$

Dimeta-heptaorthosilicate acid of calcium and aluminum in which the calcium is partially replaced by the sodium. Molecular weight 844.7.

22. Ptilotite $Si_{10}\ O_{33}\ Al_2\ H_{18}\ Ca$

Dimeta-octoorthosilicate acid of calcium and of aluminum in which the calcium is replaced partially by the sodium and by the potassium. Molecular weight 923.

23. Mordenite $S_{40}\ O_{33}\ Al_2\ H_{18}\ NaK$

Dimeta-octoorthosilicate acid of aluminum, of sodium and of potassium in which a small quantity of the alkalies and some times of the potassium are replaced by the calcium. Molecular weight 945.0.

In spite of occasional departures, the reported data demonstrate that zeolites are alkali or alkali earth salts of dimeta-n-orthosilico-aluminic acids, at least in their typical forms. Twenty-three zeolites answer to this conception which enables us to place them in a single series and to express their composition by chemically clear formula. In nature, the series of these silicates hold true up to 10 atoms of silicon and are interrupted only by the zeolites with 8 atoms of silicon. But, since new forms of zeolites are brought to light all the time, the series will not long remain incompleted.

The structure of the zeolites as it has been set forth by Scurti affords a means of explaining numerous other processes which occur in agricultural soil, such as the formation of alkali soils. The same applies to the influence of the zeolites on soil reaction.

PATERNO, EMANUELE 1923 *Preparation of potash salts from leucite and from other silicates of potash.* (Preparazione dei sali potassici della leucite e de altri silicati potassici.) *In* Atti della R. Accademia Nazionale dei Lincei. Ann. 320 sem. 1, s. 1, Rendiconti della Classe di Scienze Fisiche, Matematiche a Naturali, v. 33, no. 2.

Lemberg, as early as 1876, showed that leucite ($K_2\ Al_{22}\ Si\ O_4\ O_{12}$), very common in the volcanic rocks of Mount Vesuvius and of the extinct Latium volcanoes, treated with solutions of potassium chloride, or sodium carbonate, forms analcite ($H_4\ [Na_2, Ca]\ Al_2\ Si_4\ O_{14}$), which when treated with a solution of potassium chloride, regenerates hydrated leucite.

Paterno, studying the reaction systematically, has succeeded in proving that when finely pulverized leucite is heated under pressure with a small excess of sodium chloride, almost all of its potash is dissolved out so that the final solution contains a considerable amount of potassium chloride. With proper conditions of temperature, pressure and time of heating, at least 1.80 per cent of the potassium goes into solution.

This process was patented in Italy as early as 1919 and Paterno (who believes that the process in question for the extraction of potash is, on account of its simplicity, preferable to all others) draws striking analogies between his patent and others taken out abroad.

The importance of this method is clear when one considers the possibility of solving the problem of freeing Italy from the bondage of Stassfurt salts, taking account of the enormous quantity of potash contained in the Italian volcanic lavas.

PEROTTI, R. AND ZAFFATO, G. 1923 *About some root bacilli of Calendula officinalis L.* (Sui bacilli radicali della Calendula officinalis L.) *In* Atti della R. Accademia Nazionale dei Lincei. Ann. 320, sem. 1, s. 5. Rendiconti della Classe di Scienze Fisiche, Matematiche e Naturali. v. 32, no. 2.

The authors affirm that in the cortical layer of the *Calendula officinalis* L. there is a normal occurrence of bacteria, which, however, do not belong to the common soil species. The diversity of the characteristics of these forms, furthermore, leads one to presume that there takes place a gradual adaptation of these bacteria to this particular root environment ("istosfera" of the authors) (V. R. Acc. Lincei, v. 30, s. V 2, no. 3–6, p. 233). Some of them prove to possess oligonitrophilous characteristics.

PRELIMINARY PROFILE STUDIES OF CERTAIN FOREST SOILS

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INTRODUCTION

Certain investigators in soil problems (4) have recently come to the conclusion that the reaction of the top inches of soil does not necessarily indicate that of the underlying horizons of the soil. It is known that a plant may extend its roots into horizons of varying intensities of reaction and chemical composition.

It is considered that the reaction of the several horizons is brought about by the chemical action of the soil-forming processes and that the reaction is not a contributing cause of these processes.

The soil profile essentially comprises the whole thickness of the soil from the surface down to the solid rock below and is the resultant of the soil-forming processes.

Kelley (3) has found that soil acidity appears to be correlated with soil productiveness; the majority of the absorbing roots were found in the least acid horizons of the soil.

In the present investigation, from which the following results must be considered as being of a preliminary nature, an attempt has been made to ascertain if the *quality*[1] of timber is influenced to any extent by the reaction as shown in the study of soil profiles.

DISCUSSION

In considering the question of soil reaction and its possible effect on *quality* of timber it was thought that the key to the problem might be found in the

[1]*Method of denoting quality.* For the purposes of graphing and obtaining one figure to represent the *quality* of timber produced the following method has been adopted:

In each measurement of a plantation 5 trees were selected which represented the average range in height. The average height of these 5 trees was taken as the average height of the wood. This figure together with the age of the wood serves to give a point on a quality class graph. For all the measurements of plantations mentioned in this paper the quality class graphs used were those given in Bulletin 3 of the British Forestry Commission (6).

In each case this figure was reduced to that height growth which corresponds to an age of 50 years, e.g., a plantation of European Larch gave an average height of 5 trees as 70 feet, the age being 58 years; on the graph of page 76 of Bulletin 3, it will be seen that this plantation falls in class III. In order to arrive at a single figure it is necessary to find out from the graph the height growth of the plantation at 50 years, i.e., 64.

The *quality* of the plantation is then indicated by the figure 64.

TABLE 1

Profile data

MEAN HORIZON DEPTH		ACIDITY	LIME REQUIREMENT	LOSS ON IGNITION	SOIL	QUALITY, DECOMPOSITION RATIO AND REACTION
in.	*cm.*	*pH*	*per cent* $CaCO_3$	*per cent*		
Profile 1: 14-year larch at Red Hill with 9.0 cm. of soil covering						
1.0	2.5	4.1	0.76	9.7	Loam	Quality—I. 86
4.0	10.0	4.3	0.57	6.0	Loamy gravel	D. ratio—10.8 (rapid)
8.0	20.0	4.4	0.47	5.0	Loamy gravel	Reaction–stable
13.0	33.0	4.9	0.39	0.8	Loamy gravel	
Profile 2: 54-year Scots pine at Wasing with 13 cm. of soil covering						
3.0	8.0	3.9	0.84	8.1	Sandy loam	Quality—II. 50
9.0	23.0	4.8	0.46	3.6	Sandy loam	D. ratio—6.23 (slow)
14.0	36.0	4.7	0.54	3.0	Sandy loam	Reaction —unstable
18.0	46.0	4.5	0.59	2.7	Sand	
Profile 3: 33-year larch at Pamber with 7.5 cm. of soil covering						
0.5	1.2	4.7	0.59	7.3	Loam	Quality—II. 66
4.0	10.0	4.9	0.32	4.0	Loam	D. ratio—9.6 (moderate)
11.0	28.0	4.9	0.38	2.5	Loam	Reaction—unstable
18.0	46.0	5.3	0.40	3.1	Sandy gravel	
Profile 4: 42-year larch at Bigshotte with 6.5 cm. of soil covering						
1.0	2.5	4.1	0.92	11.1	Sandy loam	Quality—II. 71
5.0	13.0	4.4	0.70	6.4	Sandy loam	D. ratio—17.0 (rapid)
12.0	31.0	5.0	0.59	5.1	Sandy loam	Reaction—stable
18.0	46.0	5.0	0.24	5.5	Clay loam	
Profile 5: 93-year Scots pine at Easthampstead with 13 cm. of soil covering						
1.5	4.0	3.7	0.73	10.2	Sand	Quality—III. 45
7.0	18.0	4.1	0.16	1.2	Sand	D. ratio—7.8 (moderate)
12.0	31.0	4.2	0.49	2.9	Sand	Reaction—unstable
16.0	41.0	4.7	0.30	2.5	Sand	
Profile 6: 95-year Scots pine at Red Lodge with 8.5 cm. of soil covering						
1.5	4.0	4.0	0.32	5.8	Sand	Quality—III. 48
6.0	15.0	4.3	0.27	1.9	Sandy gravel	D. ratio—6.8 (moderate)
11.0	28.0	4.9	0.19	1.6	Sand	Reaction—stable
16.0	41.0	5.1	0.05	0.9	Sandy gravel	
Profile 7: 76-year larch at South Hill with 10 cm. of soil covering						
3.0	8.0	4.7	0.16	2.6	Sand	Quality—V. 44
9.0	23.0	4.8	0.40	4.4	Sandy gravel	D. ratio—2.6 (slow)
14.0	36.0	4.6	0.27	1.6	Sand	Reaction—unstable
18.0	46.0	4.6	0.16	3.2	Clay loam	

TABLE 1—*Continued*

MEAN HORIZON DEPTH		ACIDITY	LIME REQUIREMENT	LOSS ON IGNITION	SOIL	QUALITY, DECOMPOSITION RATIO AND REACTION
in.	*cm.*	*pH*	*per cent* $CaCO_3$	*per cent*		
Profile 8: 15-year Japanese larch at Bagley with 9 cm. of soil covering						
2.0	5.0	4.1	0.76	8.5	Sand	Quality—I
6.0	15.0	4.4	0.45	4.3	Sand	D. ratio—9.4 (moderate)
10.0	26.0	4.8	0.46	3.7	Sand	Reaction—unstable
14.0	36.0	4.6	0.76	5.5	Sandy gravel	
Profile 9: 30-year Scots pine at Sutton Park with 9 cm. of soil covering						
1.5	4.0	4.5	0.70	8.9	Sand	Quality—II. 54
5.0	13.0	5.3	0.31	4.1	Sand	D. ratio—9.9 (rapid)
8.0	20.0	5.0	0.30	3.0	Sandy gravel	Reaction—stable
12.0	31.0	5.0	0.21	2.0	Sandy gravel	
Profile 10: 21-year larch at Cowpond Piece with 2 cm. of soil covering						
5.0	13.0	5.6	0.24	5.8	Sandy loam	Quality—I. 79
14.0	36.0	5.7	0.05	2.9	Loam	D. ratio—29.0 (rapid)
						Reaction—stable
Profile 11: 28-year larch at Caesar's Camp with 2.5 cm. of soil covering						
5.0	13.0	4.6	0.12	2.2	Sand	Quality—II. 73
15.0	38.0	4.7	0.39	2.8	Sand	D. ratio—8.8 (moderate)
						Reaction–stable
Profile 12: 90-year Scots pine at Childown with 10 cm. of soil covering						
5.0	13.0	4.4	0.59	6.7	Loam	Quality—II. 50
12.0	31.0	4.7	0.69	5.7	Loam	D. ratio—6.7 (slow)
						Reaction—unstable

discovery of those soil types in which the profile showed no marked sudden fluctuation in the various horizons. Where small fluctuations in the reaction, indicating stable conditions, are found in that volume of soil penetrated by the fibrous roots, it is conceivable that the tree would here be able to obtain its maximum amount of nutriment from the soil solution. Where, however, the conditions are unstable and the reaction fluctuating, factors may make their appearance which tend to prevent the maximum supply of nutriment being obtained by the tree. It must also be realized that the microörganic population of the soil is sensitive to the reaction of the medium and that fluctuations in acidity will presumably produce marked effect both on species and the numbers of such soil organisms and their resultant activity in decomposition processes.

The reaction of the soil has been ascertained by the use of the "lime requirement" method (2) and by the consideration of the pH value (1).

Ten profile soil samples were taken on the Bagshot Sand area of the Thames Valley, one from Bagley Wood near Oxford and one from Sutton Park, Warwickshire, England. The soils derived from these localities are on the whole light and sandy and are remarkable for the extreme lack of calcium carbonate. As would be expected, all show an acid reaction. The average rainfall for all these localities is approximately 760 mm. (30 in.).

The tree crops consisted of *Pinus sylvestris* and *Larix europaea*. The soil samples were not taken at definite and standard depths from the surface but were taken where there was an obvious color change in the soil; stress is laid upon the importance of dividing the profile into natural divisions. Table 1 shows the figures obtained.

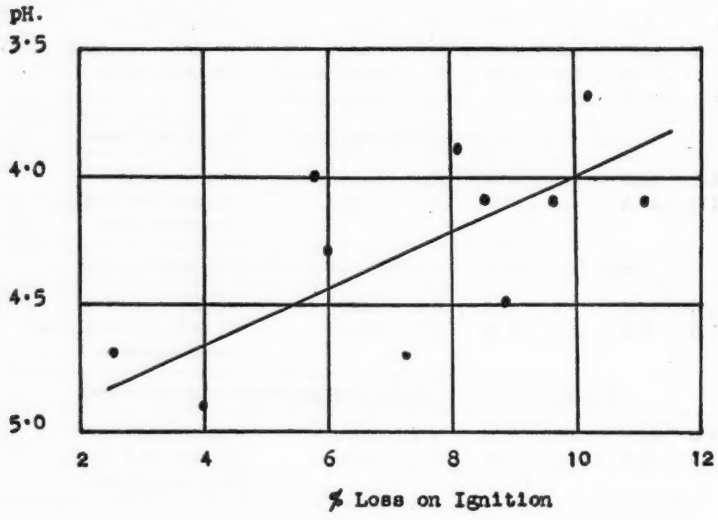

FIG. 1. RELATION BETWEEN pH AND LOSS ON IGNITION AT 0 TO 10 CM. DEPTH

Coefficient of correlation: -0.66 ± 0.11

At the outset of the investigation, only the pH value was determined and the figures obtained were plotted against the loss on ignition; Salisbury (5) has shown that under more or less uniform conditions a striking correspondence may be obtained between the pH values and loss on ignition.

Data taken from table 1 and plotted in figure 1 show a relationship between the pH values and loss on ignition at a depth of 0–10 cm. The coefficient of correlation in this case is -0.66 ± 0.11. However when the data for depths greater than 10 cm. are plotted there is no evidence of correlation, (i.e., $+0.14 \pm 0.18$ at 11–20 cm. depth, and -0.06 ± 0.22 at 31–40 cm. depth).

The presence of soil colloids affects the pH value of the soil solution without necessarily exerting any influence on the potential or titratable acidity.

TABLE 2

Lime requirement and loss on ignition

DEPTH RANGE	NUMBER OF OBSERVATIONS	COEFFICIENT OF CORRELATION
cm.		
0–10	11	+0.93 ± 0.03
11–20	10	+0.79 ± 0.08
31–40	10	+0.73 ± 0.10

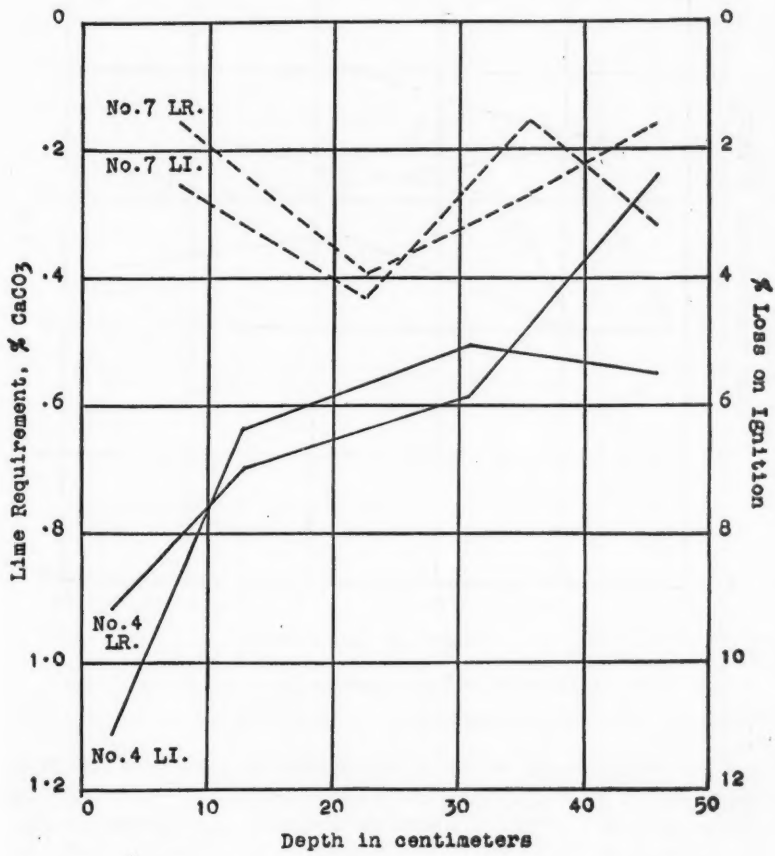

FIG. 2. LIME REQUIREMENT AND LOSS ON IGNITION GRADIENTS: PROFILES 4 AND 7
LR = lime requirement. LI = loss on ignition

As the pH values at depths greater than 10 cm. did not appear to follow the trend expected it was considered advisable to substitute lime requirement figures which would give more constant results in the presence of colloids, thus producing a better indication of the acidity present.

The data on lime requirement and the loss on ignition at various depths as shown in table 1 are tabulated in table 2 with the coefficients of correlation and it will be seen that there is a very definite relationship between lime requirement and loss on ignition at depths down to 40 cm.

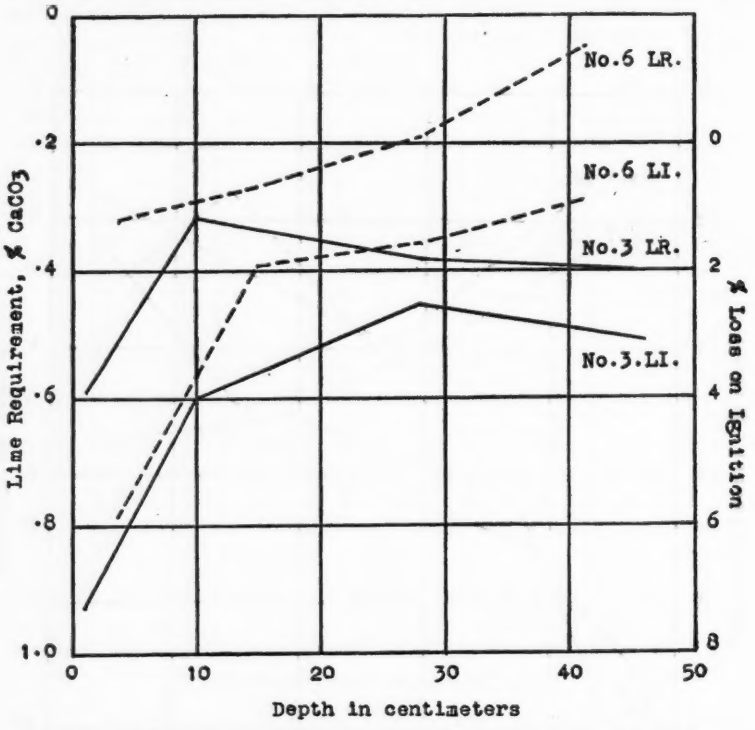

FIG. 3. LIME REQUIREMENT AND LOSS ON IGNITION GRADIENTS: PROFILES 3 AND 6
LR = lime requirement. LI = loss on ignition

A possible explanation of this relationship may be that a large amount of organic matter present in the state of a colloidal coating on the soil particles produces a greater amount of adsorption of bases and production of acidity than those soils which contain little organic matter. In other words, the greater amount of organic matter present, the greater is the lime requirement.

In the cases dealt with above, the organic matter found at the various horizons has been derived from the decomposition of the humus layer at the

surface. Where this occurred the lime requirement decreased as the loss on ignition decreased from depth to depth. But where heavy subsoils are found, such as clay loams in profiles 4 and 7, the lime requirement appears

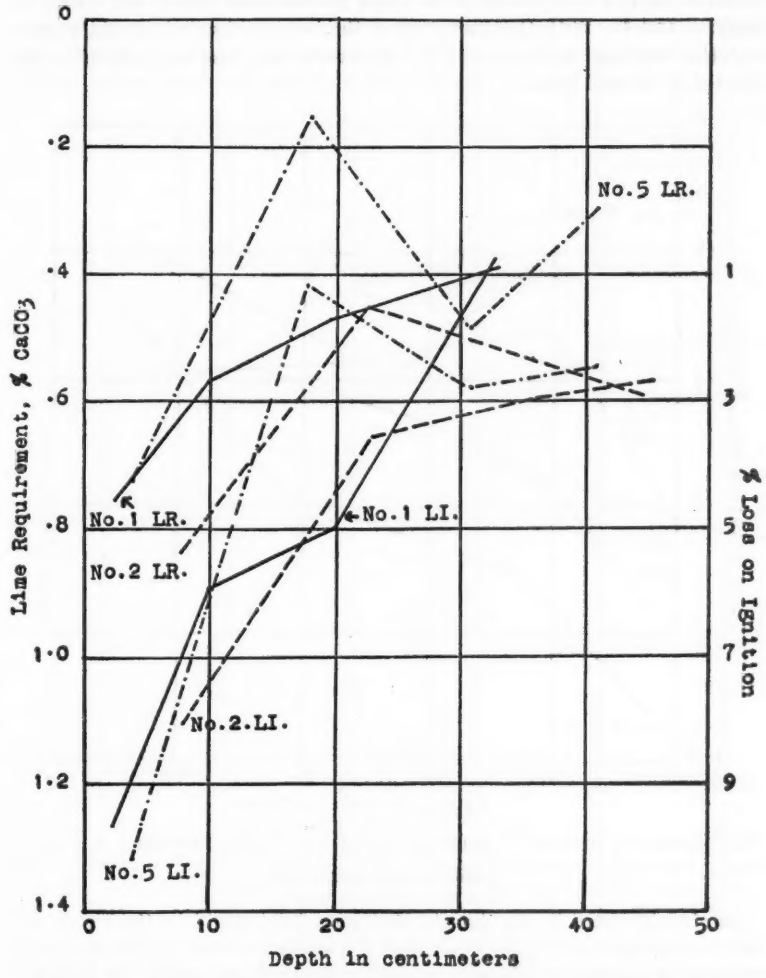

FIG. 4. LIME REQUIREMENT AND LOSS ON IGNITION GRADIENTS: PROFILES 1, 2 AND 5
LR = lime requirement. LI = loss on ignition

to decrease as the loss on ignition increases with depth. In these cases the organic matter, as expressed by the loss on ignition figure, is in all probability affected by the fact that the colloids present in the clay fraction are inorganic

in origin and possibly allow of a different type of adsorption taking place and therefore differ from the organic colloids in the lighter soil types of the higher horizons. The loss on ignition and the lime requirement gradients of these are shown in figure 2 while those of the other profiles from table 1 are shown in figures 3 and 4. With this exception of the heavy subsoils it would appear that the resulting reaction of lime requirement and loss on ignition is not affected by the soil type.

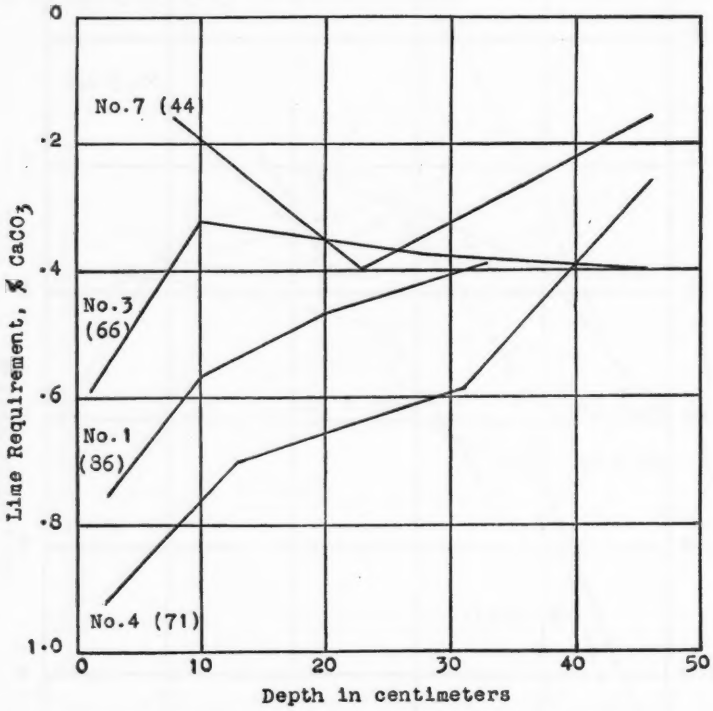

FIG. 5. EFFECT OF REACTION GRADIENT ON QUALITY OF LARCH: PROFILES 1, 3, 4 AND 7

Quality denoted in brackets

As already stated it was thought that some light might be thrown on the effect of the quality of timber produced if a study was made of the change in gradient of the lime requirement curve as the depth increased. In figures 5 and 6, the lime requirement figures of the profile have been plotted against the depth of the various horizons. The two species Scots Pine and European Larch have been shown on separate graphs. It appears from figure 5 that, in the case of larch, a marked fluctuation in the reaction seems to inhibit good growth (see profiles 3 and 7) but where the gradient is flatter (see profiles 1 and 4) better quality is produced.

In the case of Scots Pine, however, it appears from figure 6 that rapid or sudden fluctuations in the lime requirement have little or no effect on the quality and it must be assumed that there some other factor or factors are decisive in determining the quality produced. It may be, however, that in the case of Scots Pine, the horizons which have been taken are too great in depth and that if analyses had been made of 2-cm. horizons a more accurate picture of the fluctuations in reaction would be produced.

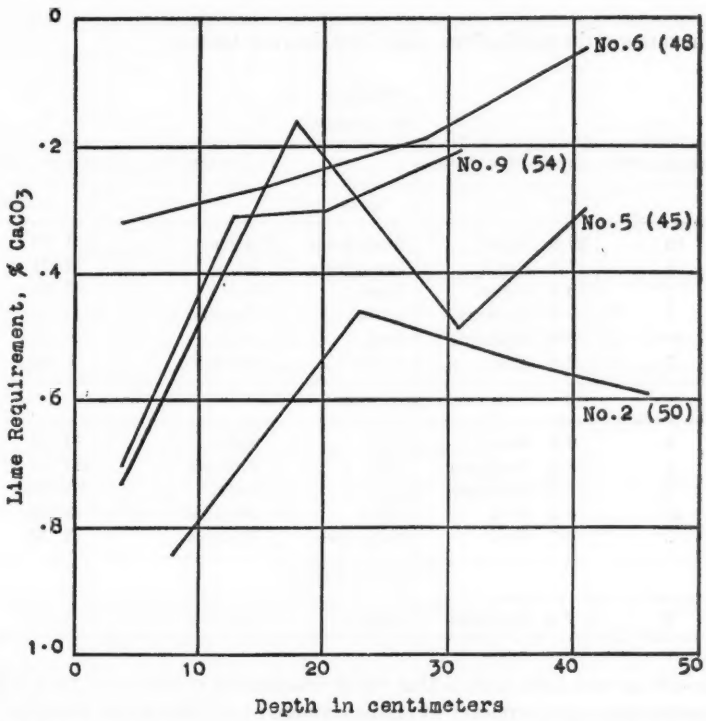

FIG. 6. EFFECT OF REACTION GRADIENT ON QUALITY OF SCOTS PINE: PROFILES 2, 5, 6 AND 9
Quality denoted in brackets

It was desired to determine the influence of rate of decomposition of the soil-covering on the fluctuations in reaction. A difficulty here presented itself in obtaining a means of expressing the rate of decomposition. The following method is put forward as a tentative measure until further investigation is made on a large number of samples, when a more definite formula will, in all probability, be forthcoming.

The organic matter content of the surface soil (0–8 cm. depth) was compared with the depth of the soil-covering. On sandy soils, when the ratio between the organic matter of

the surface soil and the depth of the soil-covering is high, thus indicating rapid decomposition, it appears that stable conditions in the soil reaction follow. This ratio of decomposition is obtained in the following manner:

In a Scots Pine wood (profile 9), 30 years old, a soil-covering of 9 cm. (0.9 decimeters) was found and the loss on ignition figure of the top of 4 cm. of soil was 8.9.

The ratio then is $\frac{8.9}{0.9} = 9.9$

When this figure 9.9 is compared with other ratios it is seen to indicate relatively rapid decomposition.

The ratios of the profiles from table 1 are shown in table 3.

TABLE 3

Soil stability

NUMBER OF PROFILE	DECOMPOSITION RATIO	SOIL	SOIL REACTION	QUALITY OF TIMBER
	Larch			
10	29.0 Rapid	Sandy loam	Stable	I. 79
4	17.0 Rapid	Sandy loam	Stable	II. 71
1	10.8 Rapid	Loam	Stable	I. 86
3	9.6 Moderate	Loam	Unstable	II. 66
11	8.8 Moderate	Sand	Stable	II. 73
7	2.6 Slow	Sand	Unstable	V. 44
	Scots Pine			
9	9.9 Rapid	Sand	Stable	II. 54
5	7.8 Moderate	Sand	Unstable	III. 45
6	6.8 Moderate	Sand	Stable	III. 48
12	6.7 Slow	Loam	Unstable	II. 50
2	6.2 Slow	Sandy loam	Unstable	II. 50
	Japanese Larch			
8	9.4 Moderate	Sand	Unstable	I.

It will be seen from table 3 that rapid decomposition (indicated by a high decomposition ratio) appears to produce stable conditions in the reaction at the various horizons. On the other hand, slow decomposition produces an unstable reaction; in these latter cases the penetration of organic matter does not compensate for the leaching action in these light soils; consequently the quality appears to be depressed in the case of larch. In the case of Scots pine, however, this impoverishment and unstable reaction does not appear to affect the quality. Where the rate of decomposition is moderate the reaction may be either stable or unstable; this is to be expected and the reaction here produced may be regarded as being a transitional stage before equilibrium is obtained.

The average decomposition ratio for the larch samples is 12.96 (rapid) and that of Scots pine is 7.45 (moderate). In connection with this, the depth of

the soil-covering under larch was compared with that under Scots pine in five woods of each species of approximately equal age. The data follows.

	SCOTS PINE	LARCH
Number	5	5
Average age	61 years	66 years
Average depth of soil covering	9.14 cm.	5.59 cm.

These data agree with the average decomposition ratios of the two species as given above.

SUMMARY

An attempt was made to ascertain if the quality of timber is influenced to any extent by the rate of decomposition of the soil-covering and the soil reaction as shown in the study of soil profiles of certain sandy soils.

The reaction has been determined by the lime requirement method and by the determination of the pH values.

There appears to be a definite correlation between the loss on ignition and the lime requirement in the soils in question down to a depth of 40 cm.

Where rapid decomposition of the soil-covering takes place little fluctuation in the acidity of the various horizons is expected, whereas slow decomposition is always associated with marked variation in the soil reaction.

The quality of larch is seen to be lowered where slow decomposition of the soil-covering and variation in soil reaction are found.

Scots pine appears to be little influenced as regards quality by fluctuation in acidity and slow decomposition.

ACKNOWLEDGMENT

The writer desires to acknowledge his thanks to Mr. C. G. T. Morison, Reader in Agricultural Chemistry, for valuable help and suggestions in connection with the laboratory work of this research carried out in the School of Rural Economy, Oxford.

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FIELD EXPERIMENTS ON THE AVAILABILITY OF NITROGENOUS FERTILIZERS 1918–1922

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The results for the first ten years of this work have been presented in earlier papers (4, 5), and the general plan of the experiment has been set forth in these publications.

The fertilizer treatments for the various plots are indicated in table 8 of this paper.

The fertilizers and manures are applied annually, the fertilizer usually being applied just before seeding time. However, in the case of fall-sown crops only one-fourth of the mineral nitrogenous fertilizer is applied at the time of seeding, the remaining three-fourths being reserved for use as a top dressing the following spring.

The primary object of the experiment has been to study the relative availability of the nitrogen in the different nitrogen-carrying materials. Also a careful study has been made of the effect of lime when used in connection with the various nitrogenous materials, in comparison with the same materials without lime. The rye straw and alfalfa hay were used for the purpose of comparing a legume and a non-legume as sources of organic matter and also to study the relative availability of the nitrogen in the two materials. The manure was used in combination with the nitrate of soda as a means of studying possible denitrification in the presence of a large amount of organic matter.

The 5-year rotation originally adopted—corn, 2 years of oats, 1 year of wheat and 1 of timothy (later changed to corn, oats, wheat and 2 years of timothy) —is one that is not now generally used in this state. It has been continued, however, since in a general way it follows the plan of cylinder experiments which were inaugurated at this station 10 years before this work was started.

Since the plan includes a study of the availability of nitrogen in different commercial materials, it is evident that a legume crop could not be included in the rotation, even though normally such would be recommended.

In addition to the other work nitrate determinations have been made on samples of soil from a number of the plots and a thorough study has been made of the soil reaction and total nitrogen content.

The results for the third 5-year period will be discussed under the following headings:

a. Yield of dry matter.
b. Percentage of nitrogen in dry matter.
c. Total yield of nitrogen.
d. Percentage of nitrogen recovered.
e. Percentage of nitrogen in the soil.

YIELD OF DRY MATTER

The yields of dry matter for the different crops, calculated on the acre basis, for the period 1918-1922 are given in table 1.

Before the results as given in this table are discussed, it should be explained that a period of rainy weather about the time the oats crop of 1919 was ready to be harvested, caused heavy losses through shattering, and on this account the figures do not represent the actual yields. Therefore, in making up the total yields and total nitrogen the figures for this crop have been omitted. It should also be explained that the barley crop of 1920 was put in to replace the regular wheat crop which was so much injured, on some of the plots, by the cold weather of 1919-1920, that it would have been impossible to draw any conclusions from the results even if it had been carried through to maturity.

Attention may be called to the fact that for the unlimed section (A), the plots that have received manure or manure and nitrate, have given the largest total yields. These high yields, however, have been obtained at a wasteful expenditure of nitrogen. This may be illustrated by citing results from specific plots. Plot 9A receives annual applications of nitrate of soda equivalent to 50 pounds of nitrogen per acre and the total yield amounts to 18,024 pounds per acre; on the other hand plot 6A receives annual applications of farm manure equivalent to more than 200 pounds of nitrogen per acre and the total yield amounts to 23,526 pounds per acre. Thus quadrupling the amount of nitrogen gave a comparatively small increase in crop yields. Expressed in other words, excessive applications of nitrogen may give increased yields, but such increases may involve an economic loss. In the case of grain or hay there is usually a further loss, due to lodging caused by excessive amounts of nitrogen.

Plot 17A shows only a small increase over the check plot. This must be attributed to the fact that this plot receives its nitrogen in the form of rye straw, and although the total amount of nitrogen thus applied is greater than the amount applied in the form of nitrate of soda, its slow availability makes it of little effect. It is interesting to compare this plot with 16A which receives an amount of alfalfa hay equal to the rye straw applied to 17A. Since the alfalfa hay contains a higher percentage of nitrogen than the straw and since it is in a more available form, it would be expected that the yields from 16A would be larger than the yields from 17A. The figures in the table bear this out, 16A showing a total increase over the check amounting to 7419 pounds, whereas the increase for 17A is only 1386 pounds per acre.

The influence of the sulfate of ammonia on 11A, where no lime has been used, is very pronounced, the total yield being less than the yield on the check plots.

On this plot the barley crop of 1920 was practically a failure as was also the hay crop of 1921. From the table it will be noted that of the 2170 pounds of hay, 1720 pounds were of the second cutting which was largely horse sorrel and crab grass. The hay crop of 1922 was likewise largely weeds. As pointed out in an earlier paper (1) the soil on this plot has become very acid, having a

TABLE 1

Yield of dry matter—5-year period, 1918–1922

(Calculated to acre basis)

PLOT NUMBER	CORN—1918			OATS—1919		BARLEY—1920		TIMOTHY—1921	TIMOTHY—1922	TOTAL FOR 5 YEARS†	INCREASE OVER CHECK
	Grain	Stalks	Cobs	Grain	Straw	Grain	Straw				
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1A	2,308	1,584	465	440	1,400	796	884	770	1,000	9,207	74
2A	2,132	1,566	361	600	1,360	860	1,020	874	940	9,113	Loss
3A	2,380	1,608	417	760	1,840	920	1,100	1,390	1,140	10,795	1,662
4A	1,928	1,692	324	720	1,560	940	1,080	1,270	1,140	9,934‡	Check
5A	2,480	2,550	432	240	2,840	1,520	2,340	4,050*	5,600	21,812	12,679
6A	2,820	2,428	458	240	2,640	1,776	2,784	5,780*	4,840	23,526	14,393
7A	1,304	1,028	295	280	560	81	134	151	328	3,881	Loss
8A	2,004	1,982	332	360	1,800	1,036	1,304	1,090	2,280	11,828	2,695
9A	2,440	1,908	436	320	2,680	1,308	1,892	2,880	4,480	18,024	8,891
10A	2,292	1,674	371	360	2,520	1,256	1,764	3,240	4,520	17,637	8,504
11A	748	658	155	680	2,160	56	544	2,170*	1,100	7,591	Loss
12A	2,564	1,880	402	520	2,280	1,452	1,788	2,460	2,640	15,466	6,333
13A	2,576	1,974	409	600	2,640	1,112	1,568	2,700	3,440	16,419	7,286
14A	2,704	2,416	401	880	3,480	1,348	1,732	2,960	3,600	18,641	9,508
15A	2,248	1,890	401	880	2,080	1,132	1,548	1,360	2,640	13,299	4,166
16A	2,876	2,478	498	520	2,480	1,248	1,652	2,080	3,240	16,552	7,419
17A	1,952	1,880	307	240	1,280	864	1,036	1,580	1,620	10,519	1,386
18A	2,808	2,888	508	560	2,240	1,888	2,492	4,340*	5,320	22,484	13,351
19A	1,816	1,792	294	680	1,360	604	936	870	660	8,332‡	Check
20A	2,684	2,408	458	480	2,640	1,160	1,460	3,900	5,080	19,790	10,657
Average	2,253	1,914	386	518	2,092	1,068	1,453	2,296	2,780	14,243	6,600

* 5A, credit 790 pounds of the total for this year to second cutting of hay.
6A, credit 1500 pounds of the total for this year to second cutting of hay.
11A, credit 1720 pounds of the total for this year to second cutting of hay.
18A, credit 1580 pounds of the total for this year to second cutting of hay.

† Oat grain omitted from total.

‡ Averaged for check.

pH value of about 4.7, and contains an abnormal amount of water-soluble aluminum, which undoubtedly has much to do with the poor yields. This plot (11A) stands in very sharp contrast to 11B which receives the same sulfate of ammonia treatment, but which is limed at intervals of 5 years. The total yield on 11B was 20,058 pounds, which is within about 1000 pounds of the yield on the nitrate of lime plot and about 1500 pounds more than the

yield on the corresponding nitrate of soda plot. The reaction of the soil from this plot is about 6.6. On being leached with distilled water it gave no test for aluminum compounds.

The average for the total yields from the limed plots is approximately 200 pounds more than the average for the unlimed plots. This is not a large increase for the lime, but it must be remembered that there are no legumes in the rotation.

TABLE 1—*Continued*

PLOT NUMBER	CORN—1918			OATS—1919		BARLEY—1920		TIMOTHY—1921	TIMOTHY—1922	TOTAL FOR 5 YEARS†	INCREASE OVER CHECK
	Grain	Straw	Cobs	Grain	Straw	Grain	Straw				
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1B	2,086	1,686	429	520	1,120	320	540	620	760	7,561	Loss
2B	2,280	1,764	421	640	1,440	932	1,068	1,110	980	9,995	Loss
3B	2,238	1,792	406	480	1,400	332	568	1,020	900	8,656	Loss
4B	2,228	2,006	398	600	1,280	768	952	1,280	1,720	10,632‡	Check
5B	2,349	2,648	476	120	2,600	1,416	1,984	2,840*	4,720	19,033	7,321
6B	2,645	2,352	452	600	2,200	1,412	2,468	3,420*	5,020	19,969	8,257
7B	2,329	1,746	404	680	1,280	568	752	650	960	8,689	Loss
8B	2,364	1,894	444	720	2,120	1,068	1,492	2,240	3,720	15,342	3,630
9B	2,316	2,406	397	440	2,440	1,244	1,796	2,960	5,040	18,599	6,887
10B	2,794	2,620	496	560	2,760	1,284	2,016	3,700	5,360	21,030	9,318
11B	2,714	2,406	478	720	2,680	1,360	2,120	3,620	4,680	20,058	8,346
12B	2,324	2,458	417	720	2,680	1,432	2,108	3,140	3,520	18,079	6,367
13B	2,227	2,490	444	680	2,840	1,240	1,840	3,000	3,560	17,641	5,929
14B	2,319	2,374	438	560	2,760	1,080	1,820	3,040	3,660	17,491	5,779
15B	2,533	2,352	451	680	2,040	1,156	1,724	2,540	3,560	16,356	4,644
16B	2,407	2,316	500	600	2,920	1,260	1,860	2,650*	4,580	18,493	6,781
17B	3,104	2,434	524	440	1,520	1,340	1,660	2,860*	3,760	17,202	5,490
18B	3,130	2,828	498	760	4,080	2,040	3,220	4,980*	5,200	25,976	14,264
19B	2,608	2,218	436	600	1,480	960	1,040	1,650	2,400	12,792‡	Check
20B	2,893	2,334	523	680	2,680	1,164	1,336	3,380	5,160	19,470	7,758
Average	2,494	2,256	452	590	2,216	1,119	1,618	2,535	3,463	16,153	7,198

* 5B, credit 720 pounds of the total for this year to second cutting of hay.
6B, credit 260 pounds of the total for this year to second cutting of hay.
16B, credit 490 pounds of the total for this year to second cutting of hay.
17B, credit 740 pounds of the total for this year to second cutting of hay.
18B, credit 1540 pounds of the total for this year to second cutting of hay.
† Oat grain omitted from total.
‡ Averaged for check.

The large total yield from 18B reflects the influence of the heavy application of manure together with the nitrate of soda. From this plot a second cutting of hay was taken in 1921 at the rate of 1540 pounds per acre. Four other plots in this section also yielded a second cutting of hay.

The yields of hay on 17B were much increased by the appearance, on this plot, of a large amount of volunteer clover. This was due to the fact that in

the presence of a limited supply of slowly available nitrogen, clover could come in where there was a liberal supply of lime, phosphate and potash. Practically no volunteer clover could be found on 17A where no lime was used. Following the timothy, more or less volunteer clover appeared on all the limed plots in 1920 and 1921, but its growth was generally better on those plots where nitrogen was deficient, since here it did not have so much competition from the timothy. It is recognized that the appearance of this clover has to a con-

TABLE 2

Percentage of nitrogen in the crops—5-year period, 1918–1922

PLOT NUMBER	CORN—1918			OATS—1919		BARLEY—1920		TIMOTHY—1921	TIMOTHY—1922
	Grain	Stalks	Cobs	Grain	Straw	Grain	Straw		
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1A	1.424	0.712	0.225	1.832	0.488	1.772	0.716	1.108	1.174
2A	1.255	0.618	0.251	1.967	0.403	1.684	0.623	1.027	0.989
3A	1.349	0.749	0.225	1.947	0.430	1.672	0.655	0.962	1.174
4A	1.416	0.693	0.251	1.921	0.493	1.643	0.603	0.864	1.118
5A	1.723	1.056	0.307	2.504	0.967	1.893	0.635	0.962*	0.811
6A	1.674	0.936	0.262	2.439	0.769	1.933	0.865	0.929*	0.859
7A	1.225	0.730	0.244	1.871	0.690	1.913	1.319	1.369	0.914
8A	1.395	0.712	0.244	2.131	0.505	1.631	0.583	0.962	0.843
9A	1.517	0.861	0.244	2.293	0.761	1.724	0.663	0.913	0.622
10A	1.420	0.712	0.251	2.362	0.899	1.732	0.603	0.864	0.729
11A	1.367	0.831	0.213	2.235	1.255	1.772	1.520	0.971*	1.319
12A	1.517	0.824	0.262	2.151	0.710	1.865	0.696	0.913	1.060
13A	1.469	0.880	0.225	2.305	0.730	1.913	0.704	0.848	0.930
14A	1.619	0.831	0.251	2.274	0.730	1.905	0.684	0.864	0.973
15A	1.574	0.918	0.206	2.228	0.690	1.845	0.635	1.151	0.892
16A	1.649	1.123	0.233	2.284	0.742	1.865	0.523	1.053	0.794
17A	1.443	0.880	0.262	1.959	0.552	1.712	0.523	0.929	0.752
18A	1.761	1.412	0.251	2.708	1.353	1.946	0.635	0.994*	0.947
19A	1.281	0.786	0.307	2.024	0.544	1.643	0.684	1.011	1.248
20A	1.544	1.018	0.318	2.247	0.722	1.772	0.503	0.808	0.655
Average	1.481	0.864	0.252	2.179	0.722	1.792	0.719	0.975	0.940

* 5A, second crop contained 1.672 per cent nitrogen.
6A, second crop contained 1.786 per cent nitrogen.
11A, second crop contained 0.945 per cent nitrogen.
18A, second crop contained 1.460 per cent nitrogen.

siderable extent modified the results of the experiment, but it would have been difficult to keep the clover out, and furthermore, it is just what might happen in general farm practice where lime and mineral fertilizers are properly used. It is thus made clear that clover may be grown with little difficulty when the conditions are made favorable.

The total yield on plot 7B is more than twice as great as that on 7A. This large increase is undoubtedly due in part to a slight difference in the soil and in part to the lime which was applied to 7B. In this connection it may be

pointed out that the yields on 1B and 7B are in much closer agreement than the yields on 1A and 7A.

From the figures given in the two tables it is very evident that had it been possible to keep the limed plots entirely free from clover, and excepting 11A and 11B, the difference in yields on the two sections would have been slight.

TABLE 2—*Continued*

PLOT NUMBER	CORN—1918			OATS—1919		BARLEY—1920		TIMOTHY—1921	TIMOTHY—1922
	Grain	Stalks	Cobs	Grain	Straw	Grain	Straw		
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1B	1.424	0.992	0.258	1.967	0.604	1.974	1.319	1.141	0.956
2B	1.377	0.618	0.306	1.863	0.395	1.759	0.583	1.102	1.200
3B	1.432	0.850	0.298	1.921	0.493	1.863	1.045	0.994	1.021
4B	1.414	0.618	0.238	1.890	0.414	1.752	0.523	0.994	1.287
5B	1.723	1.161	0.306	2.036	0.801	1.937	0.535	1.053*	1.044
6B	1.714	1.011	0.397	2.247	0.769	2.000	0.543	1.004*	1.044
7B	1.358	0.644	0.246	1.844	0.544	1.833	0.724	1.190	0.956
8B	1.525	0.918	0.238	2.055	0.571	1.796	0.483	0.945	0.665
9B	1.497	1.030	0.318	2.304	0.880	1.796	0.483	0.929	0.665
10B	1.613	1.217	0.338	2.351	0.848	1.833	0.503	0.913	0.648
11B	1.583	0.944	0.318	2.420	0.761	1.870	0.535	0.929	0.811
12B	1.592	0.906	0.357	2.173	0.631	1.740	0.483	1.027	1.238
13B	1.694	0.880	0.318	2.451	0.807	1.814	0.474	0.848	0.898
14B	1.667	0.899	0.338	2.082	0.853	1.844	0.454	0.897	0.956
15B	1.574	1.040	0.318	2.133	0.795	1.844	0.442	0.815	0.827
16B	1.732	1.273	0.298	2.304	0.776	1.881	0.495	0.971*	0.849
17B	1.630	0.899	0.298	2.145	0.730	1.963	0.535	1.086*	1.352
18B	1.787	1.330	0.338	2.550	1.229	2.037	0.615	1.011*	0.973
19B	1.574	0.786	0.258	1.966	0.634	1.926	0.523	0.955	1.816
20B	1.667	0.936	0.298	2.224	0.864	1.789	0.535	0.874	0.811
Average	1.579	0.948	0.304	2.146	0.720	1.863	0.592	0.984	1.001

* 5B, second crop contained 1.353 per cent nitrogen.
6B, second crop contained 1.581 per cent nitrogen.
16B, second crop contained 1.314 per cent nitrogen.
17B, second crop contained 1.809 per cent nitrogen.
18B, second crop contained 1.395 per cent nitrogen.

PERCENTAGE OF NITROGEN IN THE CROPS

The percentages of nitrogen in the dry matter of the various crops for the 5-year period have been determined and are shown in table 2. With slight exception the averages for the limed section are in fair agreement with the averages for the unlimed section. In the case of both sections there are some rather wide variations where the fertilizer treatment has been abnormal in amount or kind. For example, the general average percentage of nitrogen in the oats straw for 1919 is 0.722 per cent, whereas the percentage in the straw from plot 11A for the same year is 1.225. The general average for the

barley straw in 1920 is 0.719 and the percentage in the straw from 11A for the same year is 1.52, which is more than double the general average.

The crops from plots 18A and 18B generally show a higher percentage of nitrogen than the average. This is undoubtedly due to the fact that these plots receive annual applications of manure and nitrate of soda which furnish nitrogen at the rate of more than 200 pounds per acre. This heavy application is usually reflected in higher percentages of nitrogen in the dry matter. Likewise it frequently happens that those plots that receive no nitrogen show an unusually high percentage of nitrogen in the dry matter. With the exception of 11A, plots which receive equivalent amounts of nitrogen usually show about equal percentages in the dry matter.

TOTAL YIELD OF NITROGEN

The total nitrogen returned by the various crops and the total for the rotation are shown in table 3. With only few exceptions the averages for the various crops are greater for the limed section than for the unlimed section. The largest total yield of nitrogen for both sections is from plot 18 (limed and unlimed), and the next largest from plots 5 and 6 (limed and unlimed). As pointed out all of these plots have received manure at the rate of 16 tons per acre annually, and 18A and 18B have received nitrate of soda in addition, at the rate of 320 pounds per acre annually. These large returns, as suggested, do not necessarily mean profitable returns.

The normal nitrogen returned for the 5 years, from the unlimed section, appears to be about 160 to 175 pounds per acre, or between 30 and 35 pounds per acre annually. For the limed section the normal return for the same period appears to be about 175 to 200 pounds per acre, or an annual average of close to 40 pounds to the acre.

The low nitrogen yield on plot 7A is explained by the low crop yields already referred to. The yield from plot 11A is approximately half what may be considered the normal yield for the unlimed series. This, as previously explained, is due to the unfavorable soil conditions brought about by the continuous use of ammonium sulfate without lime. The yield from plot 17A is only a little in excess of the yield from the check plot. This gives indication of the low availability of the nitrogen in the rye straw. The corresponding limed plot (17B) returned a total of 207.47 pounds of nitrogen which is more than twice the amount returned by 17A. The reason for this high return is to be found in the volunteer clover which appeared on plot 17B following the timothy crops. The high return from plot 19B must likewise be credited in part to the volunteer clover which followed the timothy.

A more satisfactory comparison is made by bringing together the results from the plots that have received equivalent amounts of the nitrogenous fertilizers. The figures for the unlimed and corresponding limed sections are shown in table 4. Omitting plot 11A, which is abnormal, it will be noted

that the average of the total yields for the 5-year period on the unlimed section is 162.65 pounds, while the average total for all the limed plots is 181.37 pounds.

Omitting 11A as above, the tankage gave the lowest total yield in both sections, while in the unlimed section the nitrate of soda, nitrate of lime and cal-

TABLE 3

Yield of nitrogen—5-year period, 1918–1922

(Calculated to acre basis)

PLOT NUMBER	CORN—1918			OATS—1919			BARLEY—1920			TIMOTHY—1921	TIMOTHY—1922	TOTAL FOR 5 YEARS‡	INCREASE OVER CHECK
	Grain	Stover†	Total	Grain	Straw	Total	Grain	Straw	Total				
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1A	28.25	12.33	40.57	8.06	6.83	14.89	14.11	6.33	20.44	8.53	11.74	88.11	1.99
2A	26.66	10.59	37.24	11.80	5.48	17.28	14.48	6.35	20.83	8.98	9.30	81.83	
3A	31.11	12.98	44.09	14.80	7.91	22.71	15.38	7.21	22.59	13.37	13.38	101.34	15.22
4A	27.30	12.54	39.84	13.83	7.69	21.52	15.44	6.51	21.95	10.97	12.75	93.20§	Check
5A	42.73	28.26	70.98	6.01	27.46	33.47	28.77	14.86	43.63	44.57*	45.42	232.06	145.94
6A	47.21	23.93	71.23	5.85	20.30	26.15	34.33	24.08	58.41	66.55*	41.58	258.07	171.95
7A	15.97	8.22	24.20	5.24	3.85	9.09	1.55	1.77	3.32	2.07	3.00	36.44	
8A	27.96	14.92	42.88	7.67	9.09	16.76	16.90	7.60	24.50	10.49	19.22	106.18	20.06
9A	37.02	17.44	54.46	7.34	20.39	27.73	22.55	12.54	35.09	26.29	27.87	164.10	77.98
10A	32.55	12.84	45.39	8.50	22.65	31.15	21.75	10.64	32.39	27.99	32.95	161.37	75.25
11A	10.23	5.80	16.02	15.20	27.11	42.31	0.99	8.27	9.26	20.62*	14.51	87.52	1.40
12A	38.90	16.54	55.44	11.19	16.19	27.38	27.08	12.44	39.52	22.46	27.98	161.59	75.47
13A	37.84	18.29	56.13	13.83	19.27	33.10	21.27	11.04	32.31	22.90	31.99	162.60	76.48
14A	43.78	21.09	64.86	20.01	25.40	45.41	25.68	11.85	37.53	25.57	35.03	188.39	102.27
15A	35.38	18.18	53.56	19.61	14.35	33.96	20.89	9.83	30.72	15.65	23.55	137.83	51.71
16A	47.43	28.99	76.41	11.88	18.40	30.28	23.28	8.64	31.92	21.92	25.73	174.38	88.26
17A	28.17	17.34	45.52	4.70	7.07	11.77	14.79	5.42	20.21	14.68	12.18	99.66	13.54
18A	49.45	42.06	91.51	15.16	30.31	45.47	36.74	15.82	52.56	50.50*	50.38	275.26	189.14
19A	23.26	15.02	38.28	13.76	7.40	21.16	9.92	6.40	16.32	8.80	8.24	79.04§	Check
20A	42.53	25.97	68.50	10.79	19.06	29.85	20.56	7.34	27.90	31.51	33.27	180.24	94.12
Average‖	37.23	20.83	58.06	11.27	19.79	31.06	22.54	11.46	34.00	28.69	30.12	170.66	84.54

* Plot 5A, credit 13.21 pounds of total N for this year to second cutting of hay.
Plot 6A, credit 26.79 pounds of total N for this year to second cutting of hay.
Plot 11A, credit 16.25 pounds of total N for this year to second cutting of hay.
Plot 18A, credit 23.07 pounds of total N for this year to second cutting of hay

† Stalks and cobs.

‡ Nitrogen in oat grain omitted.

§ Averaged for check.

‖ Average of nitrogen-treated plots (5A to 20A, with the exception of 7A and 19A).

cium cyanamide gave results which agree closely. In the limed section the highest total yield was 204.23 pounds with nitrate of lime and the next highest 195.93 pounds with ammonium sulfate. On the limed section the average yields with the mineral nitrogenous fertilizers surpassed those with the

organic nitrogenous fertilizers by about 20 pounds per acre. This is in accord with results previously reported.

Omitting the corn which is a rather heavy nitrogen feeder and allowing for the nitrogen in the oats grain (not included in the table) it will be seen that

TABLE 3—*Continued*

PLOT NUMBER	CORN—1918			OATS—1919			BARLEY—1920			TIMOTHY—1921	TIMOTHY—1922	TOTAL FOR 5 YEARS‡	INCREASE OVER CHECK
	Grain	Stover†	Total	Grain	Straw	Total	Grain	Straw	Total				
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1B	29.71	17.84	47.55	10.23	6.76	16.99	6.32	7.12	13.44	7.07	7.27	82.09	
2B	31.40	12.19	43.59	11.92	5.69	17.61	16.39	6.23	22.62	12.23	11.76	95.89	
3B	32.05	16.42	48.47	9.22	6.90	16.12	6.19	5.94	12.13	10.14	9.19	86.83	
4B	35.99	13.35	49.34	11.34	5.30	16.64	13.45	4.98	18.43	12.72	22.14	107.93§	Check
5B	40.47	40.20	80.67	2.44	20.83	23.27	27.43	10.61	38.04	32.06*	49.28	220.88	112.95
6B	45.34	25.57	70.91	13.48	16.92	30.40	28.24	13.40	41.64	35.84*	52.41	217.72	109.79
7B	31.62	12.23	43.85	12.54	6.96	19.50	10.41	5.44	15.85	7.74	9.18	83.58	
8B	36.05	18.45	54.50	14.80	12.11	26.91	19.18	7.21	26.39	21.17	24.74	138.91	30.98
9B	34.67	26.04	60.71	10.14	21.47	31.61	22.34	8.67	31.01	27.50	33.01	173.70	65.77
10B	45.07	33.57	78.64	13.17	23.40	36.57	23.54	10.14	33.68	33.78	34.73	204.23	96.30
11B	42.96	24.23	67.19	17.42	20.39	37.81	25.43	11.34	36.77	33.63	37.95	195.93	88.00
12B	37.00	23.76	60.76	15.65	16.91	32.56	24.92	10.18	35.10	32.25	43.58	188.60	80.67
13B	37.72	23.32	61.04	16.67	22.92	39.59	22.49	8.72	31.21	25.45	31.97	172.59	64.66
14B	38.66	22.82	61.48	11.66	23.54	35.20	19.92	8.26	28.18	27.27	34.99	175.46	67.66
15B	37.87	25.89	63.76	14.50	16.22	30.72	21.32	7.62	28.94	20.70	29.44	159.06	51.13
16B	41.70	30.97	72.67	13.82	22.66	36.48	23.70	9.21	32.91	27.41*	38.88	194.53	86.60
17B	50.50	23.44	73.94	9.44	11.10	20.54	26.30	8.88	35.18	36.41*	50.84	207.47	99.54
18B	55.93	39.29	95.22	19.38	50.14	69.52	41.55	19.80	61.35	56.26*	50.60	313.57	205.64
19B	41.05	18.56	59.61	11.80	9.38	21.18	18.49	5.44	23.93	15.76	43.58	152.26	Check
20B	48.33	23.41	71.74	15.12	23.16	38.28	20.82	7.15	27.97	29.54	41.85	194.26	86.33
Average‖	42.31	27.21	69.52	13.41	21.56	34.97	24.80	10.08	34.88	31.38	39.59	196.92	88.99

* Plot 5B, credit 9.74 pounds of total N for this year to second cutting of hay.
Plot 6B, credit 4.11 pounds of total N for this year to second cutting of hay.
Plot 16B, credit 6.44 pounds of total N for this year to second cutting of hay.
Plot 17B, credit 13.39 pounds of total N for this year to second cutting of hay.
Plot 18B, credit 21.48 pounds of total N for this year to second cutting of hay.

† Stalks and cobs.

‡ Nitrogen in oat grain omitted.

§ 4B taken as check in this series.

‖ Average of nitrogen-treated plots (5B to 20B, with the exception of 7B and 19B).

the crops average a little better than 30 pounds of nitrogen removed per acre annually. If allowance be made for loss through leaching and otherwise, twice this amount would be required for the average crop. This would be equivalent to about 400 pounds of nitrate of soda per acre, which is decidedly more than is commonly used for general farm crops. The inevitable conclu-

sion is that a wider use should be made of crops which utilize atmospheric nitrogen if crop yields are to be kept on a high plane and the nitrogen supply of the soil maintained. Of the crops grown in this rotation corn used the most nitrogen. The average amount removed by the entire corn crop from the unlimed section was 54.97 pounds and from the limed section 64.8 pounds per acre.

TABLE 4

Total yields of nitrogen from plots which receive nitrogenous fertilizers in equivalent amounts —1918–1922

	PLOT NUMBER	CORN—1918	OATS (STRAW)*—1919	BARLEY—1920	TIMOTHY—1921	TIMOTHY—1922	TOTAL*
		pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
		Mineral nitrogenous fertilizer					
Unlimed	9A	54.46	20.39	35.09	26.29	27.87	164.10
	10A	45.39	22.65	32.39	27.99	32.95	161.37
	11A	16.02†	27.11†	9.26†	20.62†	14.51†	87.52†
	12A	55.44	16.19	39.52	22.46	27.98	161.59
		Organic nitrogenous fertilizer					
	13A	56.13	19.27	32.31	22.90	31.99	162.60
	14A	64.86	25.40	37.53	25.57	35.03	188.39
	15A	53.56	14.35	30.72	15.65	23.55	137.83
Average		54.97	19.71	34.59	23.49	29.89	162.65
		Mineral nitrogenous fertilizers					
Limed	9B	60.71	21.47	31.01	27.50	33.01	173.70
	10B	78.64	23.40	33.68	33.78	34.73	204.23
	11B	67.19	20.39	36.77	33.63	37.95	195.93
	12B	60.76	16.91	35.10	32.25	43.58	188.60
		Organic nitrogenous fertilizers					
	13B	61.04	22.92	31.21	25.45	31.97	172.59
	14B	61.48	23.54	28.18	27.27	34.99	175.46
	15B	63.76	16.22	28.94	20.70	29.44	159.06
Average		64.80	20.69	32.13	28.65	35.10	181.37

* Oats grain omitted.

† 11A omitted from average.

PERCENTAGE OF NITROGEN RECOVERED IN THE CROPS

The percentage of nitrogen recovered in the crops is shown in table 5. Referring to the figures for the unlimed section, it will be noted that with the exception of the oats, which has been omitted from the rotation average, the general average for the different crops varies slightly between 21.29 per cent for barley and 25.43 per cent for corn. In other words, taking the averages, less than one-fourth of the applied nitrogen was recovered in the crops.

TABLE 5

Percentage of nitrogen recovered—5-year period, 1918–1922

PLOT NUMBER	CORN—1918	OATS—1919*	BARLEY—1920	TIMOTHY—1921	TIMOTHY—1922†	4-YEAR AVERAGE
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
5A	13.77	7.95	19.53	20.77	20.84	18.73
6A	21.98	2.99	25.94	28.14	22.35	24.60
8A	15.72	Loss	21.02	2.42	26.09	16.31
9A	31.68	14.51	31.27	33.08	30.48	31.63
10A	13.02	19.25	25.98	36.41	40.73	29.04
11A	Loss	41.37‡	Loss	21.65	3.55	6.30
12A	33.70	11.84	39.96	25.36	30.71	32.43
13A	35.12	23.13	25.82	26.23	38.79	31.49
14A	53.08	47.21	36.06	31.63	44.92	41.42
15A	29.83	24.76	22.71	11.63	21.77	21.49
16A	44.04	10.27	12.38	12.18	10.43	19.76
17A	33.82	Loss	5.82	29.25		17.22
18A	18.71	11.86	18.95	18.75	18.23	18.66
20A	11.61	12.53	12.62	32.76	28.19	21.30
Average...	25.43	16.26	21.29	23.59	24.07	23.60

* Oats omitted from average.

† The yield on plot 4 was taken as the check for this year.

‡ Per cent nitrogen in straw 1.255 (exceptionally high).

PLOT NUMBER	CORN—1918	OATS—1919*	BARLEY—1920	TIMOTHY—1921	TIMOTHY—1922†	4-YEAR AVERAGE
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
5B	11.30	2.86	13.45	10.67	17.30	13.18
6B	11.24	7.13	13.51	10.91	23.47	14.78
8B	0.12	31.37	20.43	27.94	10.48	14.74
9B	12.86	24.90	19.27	26.71	21.92	20.19
10B	49.71	34.62	24.51	39.40	25.38	34.75
11B	26.19	37.05	30.57	39.09	31.88	31.93
12B	12.94	26.88	27.29	36.31	43.22	29.94
13B	13.51	40.54	19.67	22.60	19.82	18.90
14B	14.63	31.98	13.73	26.27	25.91	20.14
15B	19.13	23.15	15.22	11.01	14.71	15.02
16B	21.45	20.16	11.37	13.33	13.46	14.90
17B	10.18	0.96	76.09‡	135.18‡	123.71‡	86.29‡
18B	14.54	24.87	22.77	19.40	13.79	17.63
20B	6.88	28.50	9.78	23.18	27.08	16.73
Average...	16.05	23.93	18.58	23.60	22.19	20.22

* Oats omitted from average.

† The yield on plot 4 was taken as the check for this year.

‡ The recovery on this plot was very much increased by the growth of volunteer clover. Omitted from average.

As would be expected, the recovery from the unlimed sulfate of ammonia plot (11A) is very low—6.3 per cent. The recovery from this plot for the first 5-year period of the experiment was 47.4 per cent and for the second 5-year period 28.7 per cent. The results for the last 5 years illustrate, in a striking manner, the cumulative effect of such treatment. It is interesting to note that the highest recovery was from plot 14A, which gets its nitrogen in the form of fish scrap. This material did not rank so high in the first and second rotations.

Nitrate of soda, nitrate of lime and calcium cyanamide all show a recovery close to 30 per cent. It is noteworthy that the calcium cyanamide used at a rate equivalent to 320 pounds of nitrate of soda per acre did not appear to cause injury. It has been customary to spread this material broadcast and harrow in just before planting.

The general average recovery for the limed series is slightly higher than for the unlimed. The low average for the corn crop of 1918 must be attributed to the volunteer clover which came in with the timothy on the check plots for the 2 years preceding the corn. This clover raised the amount of nitrogen in the check plots and thus lowered the percentage recovered from the nitrogen-treated plots. The presence of volunteer clover in the timothy crops of 1921 and 1922, on plot 17B, had a marked influence on the percentage of nitrogen recovered, causing it to appear to be more than 100 per cent. As previously explained, the presence of lime and minerals and the absence of readily available nitrogen on this plot made the conditions ideal for clover, and it was present to such an extent that it made the crop appear to be a mixture of timothy and clover, though no clover had been seeded.

The low average recovery from plots 5B and 6B indicates a heavy loss of nitrogen from the manure used on these plots. This bears out the statement previously made to the effect that excessive applications of nitrogen result in abnormal losses of this element. The corresponding plots on the unlimed section show a distinctly higher recovery.

For both the limed and unlimed sections the double portion of nitrate of soda (320 pounds per acre) gave a higher recovery than the single portion (160 pounds per acre). On the limed section the ammonium sulfate gave a higher average recovery than the nitrate of soda but not so high as the nitrate of lime. Of the plots on this section that receive an equivalent amount of nitrogen, the nitrate of lime gave the highest, and the tankage, the lowest average recovery.

FIFTEEN-YEAR SUMMARY OF NITROGEN RECOVERY

Table 6 shows the average nitrogen recovery by 5-year periods for the limed and unlimed sections. The general averages for the unlimed section are, with slight exception, very nearly the same as those for the limed section, the 15-year average for the latter being slightly over 25 per cent and for the former just a little under 25 per cent. It should be pointed out, however,

TABLE 6

Average percentage of nitrogen recovered by 5-year periods, field experiments, 1908–1922

PLOT NUMBER	A (UNLIMED)			B (LIMED)		
	First 5-year period	Second 5-year period	Third 5-year period	First 5-year period	Second 5-year period	Third 5-year period*
5	14.9	14.6	18.7	13.6	12.8	13.2
6	14.6	16.2	24.6	11.9	10.9	14.8
8	23.5	16.3	16.3	37.6	39.1	15.7
9	43.3	34.0	31.6	46.3	26.1	20.2
10	33.4	29.5	29.0	55.8	35.8	34.8
11	47.4	28.7	6.3	47.9	40.0	31.9
12	36.4	25.5	32.4	43.9	31.5	29.9
13	30.1	23.4	31.5	32.2	28.8	18.9
14	30.6	29.1	41.4	24.4	25.6	20.1
15	21.3	23.7	21.5	28.7	26.9	15.0
16	20.7	17.6	19.8	23.1	15.5	14.9
17	Loss	12.9	17.2	11.0	39.2†	86.3†
18	17.8	16.0	18.7	18.8	15.7	17.6
20	36.4	24.3	21.3	32.6	29.3	16.7
Average...	26.5	22.3	23.6	30.6	26.0	20.2

* Average for 4 years. Oats 1919 omitted.

† Omitted from average on account of volunteer clover.

TABLE 7

Average nitrogen recovered in three 5-year periods from plots that receive nitrogenous fertilizers in equivalent amounts

PLOT NUMBER	A (UNLIMED)			B (LIMED)		
	First 5-year period	Second 5-year period	Third 5-year period*	First 5-year period	Second 5-year period	Third 5-year period*
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Mineral nitrogenous fertilizers						
9	43.3	34.0	31.6	46.3	26.1	20.2
10	33.4	29.5	29.0	55.8	35.8	34.8
11	47.4	28.7	6.3†	47.9	40.0	31.9
12	36.4	25.5	32.4	43.9	31.5	29.9
Average...	40.1	29.4	31.0	48.5	33.4	29.2
Organic nitrogenous fertilizers						
13	30.1	23.4	31.5	32.2	28.8	18.9
14	30.6	29.1	41.4	24.4	25.6	20.1
15	21.3	23.7	21.5	28.7	26.9	15.0
Average...	27.3	25.4	31.5	28.4	27.1	18.0

* Four-year average, oats 1919 omitted.

† Omitted from average.

that the recovery from the plots on which manure has been used is distinctly lower than the recovery from the plots on which commercial fertilizers have been used, the manure-treated plots giving an average a little better than 15 per cent. This, therefore, tends to lower the general average.

A fairer estimate is made by comparing the results from those plots that have received equivalent amounts of nitrogen. Such comparison is made in table 7. A study of the table shows that as pointed out above, the lime has not distinctly influenced the nitrogen recovery one way or the other. There is perhaps more of a tendency towards a decreasing recovery in the second and third periods on the limed than on the unlimed section. Altogether the recovery is less with the organic than with the inorganic materials. For the limed section the highest recovery for the three periods was 42 per cent with nitrate of lime and the next highest 40 per cent with ammonium sulfate.

Considering the recovery with the mineral nitrogenous fertilizers the general average for both sections is only a little over 35 per cent; that is, of 100 pounds of nitrogen applied, scarcely more than one-third is returned in the crops removed.

PERCENTAGE OF NITROGEN IN PLOT SOILS

Table 8 shows the percentage of nitrogen in samples of soil collected in 1913, 1917, and 1922; the lime requirement by the Veitch method; and the pH values for the 1922 samples, for both the limed and unlimed sections. On comparing the averages it is at once apparent that the loss of nitrogen has been greater on the limed than on the unlimed soils, the difference being about 0.01 per cent. In this connection attention may be called to the fact that the original samples of soil from several of these plots gave a nitrogen content of about 0.11 per cent (4).

The averages of all the samples taken in 1913, 1917 and 1922 show little change during the last 10 years. Plots that have received heavy applications of manure show distinct increases, but there have been losses from other of the plots and therefore, the total changes have apparently been compensating. Attention may be called to the notable gains of nitrogen on plots 5A, 6A and 18A and the corresponding B plots. As previously noted, however, these gains have been secured by the use of far more nitrogen than the crops could utilize and it does not follow that the gains are to be considered as a profitable investment. On plots 18A and 18B, nitrate of soda was used in addition to the manure, but here the gains have been no more than where the manure was used alone, which would indicate little or no residual effect from the nitrate of soda. It is thus very evident that actually to increase the nitrogen content of the soil it is necessary to use much larger amounts of manure than would be available on the average farm. Indeed it may be questioned, in many cases at least, whether it is necessary actually to increase the nitrogen content of the soil. If sufficient nitrogenous materials could be supplied to make good all normal losses, and at the same time keep the plant in a healthy grow-

TABLE 8

Percentage of nitrogen, pH values and lime requirement—plot soils 1913–1922

PLOT NUMBER	FERTILIZER TREATMENT FOR $\frac{1}{10}$ ACRE PLOT	UNLIMED SECTION (A PLOTS)						LIMED SECTION (B PLOTS)					
		Nitrogen				pH	Lime requirement	Nitrogen				pH	Lime requirement
		Soil, 1913	Soil, 1917	Soil, 1922	Subsoil, 1922			Soil, 1913	Soil, 1917	Soil, 1922	Subsoil, 1922		
		per cent	*per cent*	*per cent*	*per cent*		*pounds*	*per cent*	*per cent*	*per cent*	*per cent*		*pounds*
1	Nothing	0.1059	0.1033	0.102	0.068	5.4	1,200	0.0862	0.0770	0.072	0.051	7.0	Alkaline
2	16 pounds muriate of potash	0.1098	0.1173	0.111	0.080	5.4	1,200	0.0871	0.0790	0.078	0.052	7.0	Alkaline
3	32 pounds acid phosphate	0.1042	0.1139	0.113	0.072	5.4	1,000	0.0821	0.0751	0.072	0.049	6.8	200
4	Minerals only*	0.1180	0.1088	0.108	0.072	5.4	1,400	0.0855	0.0779	0.077	0.061	6.9	400
5	Minerals, 1600 pounds cow manure	0.1002	0.1185	0.134	0.085	5.2	1,600	0.1030	0.1143	0.128	0.092	6.9	300
6	Minerals, 1600 pounds horse manure	0.0929	0.1230	0.137	0.097	5.1	1,600	0.1028	0.1190	0.134	0.086	6.7	600
7	Nothing	0.0790	0.0785	0.074	0.037	5.3	1,000	0.0879	0.0821	0.080	0.061	7.0	200
8	Minerals, 8 pounds $NaNO_3$	0.0880	0.0883	0.084	0.047	5.8	1,400	0.0801	0.0787	0.079	0.053	6.8	400
9	Minerals, 16 pounds $NaNO_3$	0.0921	0.0975	0.097	0.064	5.8	1,200	0.0753	0.0810	0.074	0.052	6.8	300
10	Minerals, $Ca(NO_3)_2$ equivalent to 16 pounds $NaNO_3$	0.0941	0.0903	0.092	0.066	5.8	1,000	0.0805	0.0779	0.081	0.051	6.8	400
11	Minerals, $(NH_4)_2SO_4$ equivalent to 16 pounds $NaNO_3$	0.0977	0.0904	0.095	0.061	4.8	2,400	0.0801	0.0819	0.078	0.060	6.1	1,000
12	Minerals, $CaCN_2$ equivalent to 16 pounds $NaNO_3$	0.0869	0.0844	0.086	0.048	5.8	1,000	0.0861	0.0896	0.080	0.056	6.8	200
13	Minerals, Dried blood equivalent to 16 pounds $NaNO_3$	0.0925	0.1063	0.107	0.069	5.4	1,600	0.0807	0.0826	0.078	0.048	6.6	500
14	Minerals, Fish equivalent to 16 pounds $NaNO_3$	0.1014	0.1058	0.108	0.072	5.6	1,500	0.0779	0.0889	0.081	0.060	6.6	400
15	Minerals, concentrated tankage equivalent to 16 pounds $NaNO_3$	0.0884	0.0919	0.087	0.055	5.2	1,600	0.0717	0.0803	0.075	0.061	6.6	400
16	Minerals, 800 pounds alfalfa hay	0.0891	0.1012	0.098	0.064	5.2	1,600	0.0897	0.0904	0.096	0.066	6.6	500
17	Minerals, 800 pounds rye straw	0.0950	0.0980	0.096	0.059	5.5	1,600	0.0953	0.0952	0.100	0.070	6.8	400
18	Minerals 1600 pounds cow manure and 16 pounds $NaNO_3$	0.1088	0.1170	0.132	0.074	6.0	1,000	0.1014	0.1190	0.124	0.065	6.9	Alkaline
19	Minerals only	0.0980	0.0872	0.091	0.059	5.3	1,200	0.0809	0.0784	0.082	0.050	7.0	Alkaline
20	Minerals, 800 pounds wheat or rye straw and 16 pounds $NaNO_3$	0.0959	0.0908	0.094	0.060	6.0	1,100	0.0832	0.0903	0.091	0.056	7.0	Alkaline
Average		0.0969	0.1006	0.102	0.065			0.0859	0.0879	0.088	0.060		

*Minerals = 32 pounds acid phosphate and 16 pounds muriate.

ing condition, there would seem to be little need for an actual increase in the nitrogen content of the soil. The question of normal losses is, of course, an open one. The problem, however, should become more and more one of feeding the plant for the most economical production (using the term "economical" in its broad sense) rather than of feeding the soil.

Plots 7A and 7B and likewise plots 1B to 4B inclusive, show slight decline in the nitrogen content from period to period. The fact that some of them have received annual applications of phosphate and potash has not prevented nitrogen depletion.

On the other hand plots 1A to 4A inclusive, which have likewise received no nitrogenous fertilizer or manure, show no appreciable loss of nitrogen. A possible explanation of this may be found in the fact that these plots occupy slightly lower ground than the other plots and thus received a small amount of wash from the higher ground. Furthermore, it is possible that this soil was somewhat better in the beginning. The fact that plot 1A has always given larger yields than 7A would tend to support this view.

The heavy applications of nitrogen supplied to the manured plots have had a distinct influence on the nitrogen content of the subsoil as well as on the top soil. An examination of the column reporting the subsoil for 1922 shows that the percentage of nitrogen from plots 5A and 6A and 5B and 6B are distinctly higher than any of the others, while 18A and 18B are higher than the general average. This is positive evidence that some of the nitrogen, at least, is held in the lower depths of the soil as claimed by Lawes (3). On the other hand the subsoil from plot 7A shows a very low percentage of nitrogen.

LIME REQUIREMENT AND pH VALUES

Reference to the column headed "pH" shows that none of the soils of the unlimed section has a pH above 6.0, the range being between 4.8 and 6.0. As would naturally be expected, the soil having the lowest pH is that from plot 11A where ammonium sulfate has been used regularly without lime. The majority of the soils from the unlimed section have a pH value between 5.0 and 5.5.

With the exception of plot 11A, the lime requirement varies between 1000 and 1600 pounds CaO per acre. In this connection it may be pointed out that in 1913 the average lime requirement for all of these soils was 1840 pounds CaO per acre. It would thus appear that the acidity has decreased slightly during the past 10 years. There does not appear to be a definite cause for this decrease, but it will be recalled that nearly all of these plots have received rather heavy applications of acid phosphate annually, and it is possible that there may be a connection between this and the decrease in acidity. Burgess (2) has pointed out that in certain cases the acidity was decreased by the use of acid phosphate.

It is significant that plot 3A which has regularly received acid phosphate at the rate of 640 pounds per acre has the same lime requirement as 7A and a

slightly lower requirement than 1A, both of which have received no acid phosphate. If acid phosphate tends to increase acidity, as has sometimes been claimed, then certainly plot 3A should have shown a higher acidity than 1A. The high lime requirement of plot 11A is in conformity with the low pH of this plot.

With the exception of plot 11B, the soils representing the limed section show a pH value ranging between 6.6 and 7.0, and by the Veitch test are either alkaline or show only a low lime requirement. In other words, with one exception, all of the limed soils are, for practical purposes, neutral. Since the lime (carbonate form, 2 tons per acre) was applied at the beginning of the rotation and the soil samples collected at the end of the rotation, the figures shown in the table furnish good evidence that such an application will carry over 5 years and still leave the soil in good condition.

The average lime requirement (Veitch method) for this series at the end of the first 5-year period (1913) was 1140 pounds CaO per acre. It is now practically neutral. It is evident, therefore, that there has been a distinct improvement in the soil reaction on account of the lime treatment.

SUMMARY

This paper reports the results of the third 5-year period in the nitrogen availability field experiments. The work was commenced in 1908 and therefore the third 5-year period was completed with the crop of 1922.

The object of the work has been:

a. To study the yields of dry matter and nitrogen under varying nitrogen and lime treatments.

b. To study the influence of the lime and nitrogen treatment on the percentage of nitrogen in the dry matter.

c. To study the availability of the nitrogen, in several nitrogenous materials, in a soil deficient in lime and also in one well supplied with lime.

d. To study the influence of large amounts of organic matter in the form of manure, on crop yields and on the utilization of nitrate nitrogen.

e. To study the changes in the nitrogen content of the soil under different nitrogen treatments and also with and without lime.

In nearly all cases the nitrogen treatments increased the yields as compared with the yields from the check plots.

With only a few exceptions, the total yields of dry matter for the 5-year period were very nearly as much on the unlimed as on the limed plots. The unlimed sulfate of ammonia plot furnished the most striking exception. In this connection it is to be observed that the rotation included no legume crops.

Of the four mineral nitrogenous materials used alone, calcium nitrate and ammonium sulfate gave the largest yields of dry matter and the highest nitrogen recovery on the limed section. Also on this section the mineral nitrogenous materials gave slightly higher yields of dry matter and higher nitrogen recoveries than the three commercial organic materials.

On the unlimed section manure alone gave heavier yields than on the limed section. Also on this section the percentage of nitrogen recovered from manure, when used alone, was very low (less than 15 per cent) indicating a heavy loss of nitrogen.

With excessive applications of nitrogen in the form of manure there was not only this loss of nitrogen but also a loss of grain and hay on account of lodging.

The use of a slowly available nitrogenous material, as rye straw, where lime and mineral fertilizers have been used, greatly encourages the growth of clovers (volunteer) in the stubble following grain and in the timothy sod. Even where no nitrogen was used, clover came in if the soil was well supplied with lime, phosphate and potash. On the other hand where lime was omitted very little clover came in even though phosphate and potash were applied in generous amounts.

On the unlimed section the total nitrogen recovered in the crop, where organic nitrogenous fertilizers were used, was somewhat more than where the mineral nitrogenous fertilizers were used. On the limed section the reverse was true.

With a few exceptions, the total yield of nitrogen was governed by the total yield of dry matter. Taking the nitrogen-treated plots only, the average yield of nitrogen for the 5 crops is about 35 pounds per acre for the unlimed section and about 40 pounds for the limed section.

Liming did not very greatly affect the percentage of nitrogen in the dry matter, except where volunteer clover came in with the other crops.

The percentage of nitrogen in the dry matter was considerably influenced by the nitrogen treatment. Excessive amounts of nitrogen usually gave an increased percentage in the dry matter. There was a tendency for the plots receiving no nitrogen to yield dry matter somewhat lower in nitrogen than dry matter from plots that received nitrogen treatment.

On the unlimed section there is very little difference between the average percentage of nitrogen recovered for the first and third 5-year periods, the former being 26.5 per cent and the latter 23.6 per cent. On the limed section, however, the average percentage of nitrogen recovered for the first 5-year period was 30.6 and for the third 5-year period 20.2, a difference of a little over 10 per cent.

With the exception of those plots which have received extreme treatment, there has not been much change in the nitrogen content of the soil since 1913. The average nitrogen content for the soils on the unlimed section is about 0.10 per cent and for the limed section 0.085 to 0.088 per cent. The plots which have received annual applications of manure and those that have received both manure and nitrate, show a distinct increase in nitrogen content since 1913.

With one exception the lime requirement (Veitch method) of the soils from the unlimed section varies from about 1000 to 1600 pounds per acre and the pH value from 4.8 (ammonium sulfate plot) to 6.0.

Likewise with one exception, the soils of the limed section are either alkaline or have a lime requirement not exceeding 500 or 600 pounds per acre. With slight exception these soils show a pH value varying between 6.6 and 7.0.

The results of this work strongly emphasize the following points:

a. The great difficulty in maintaining the nitrogen supply of the soil when non-legume crops only are grown.

b. The small percentage of the applied nitrogen that is recovered in the crop under field conditions, and therefore the great loss of nitrogen from soils that are constantly under cultivation.

c. The imperative need of lime in connection with fertilizers that are physiologically acid.

d. The effect of lime in depleting the nitrogen supply of the soil when no legume crops are grown.

e. The ease with which clover may be grown if the conditions are made favorable by the use of lime, phosphate and potash.

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PLATE 1

FIG. 1. Plot 11A. Ammonium sulfate applied annually without lime. Horse sorrel and crab grass have replaced timothy.

FIG. 2. Plot 11B. Ammonium sulfate applied as in 11A, but limed at intervals of 5 years. An excellent crop of timothy.

FIG. 1

FIG. 2

PLATE 2

FIG. 1. Plot 17A. Rye straw used as a source of nitrogen, but without lime. No volunteer clover to be found in this timothy sod.

FIG. 2. Plot 17B. Rye straw used as a source of nitrogen. Limed at intervals of 5 years. Volunteer clover abundant.

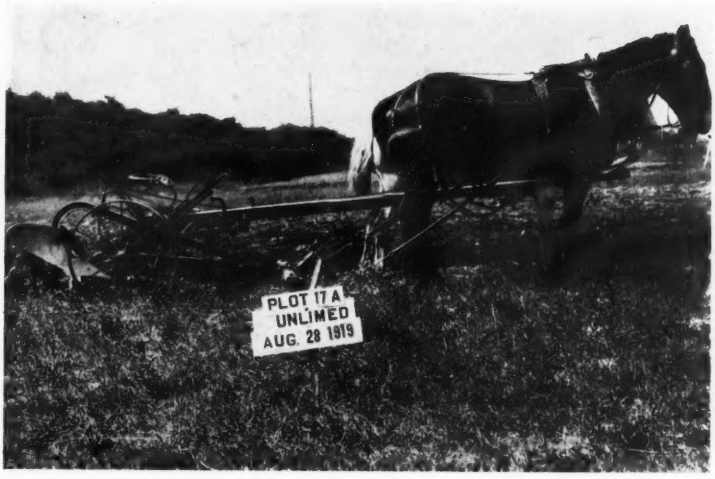

FIG. 1

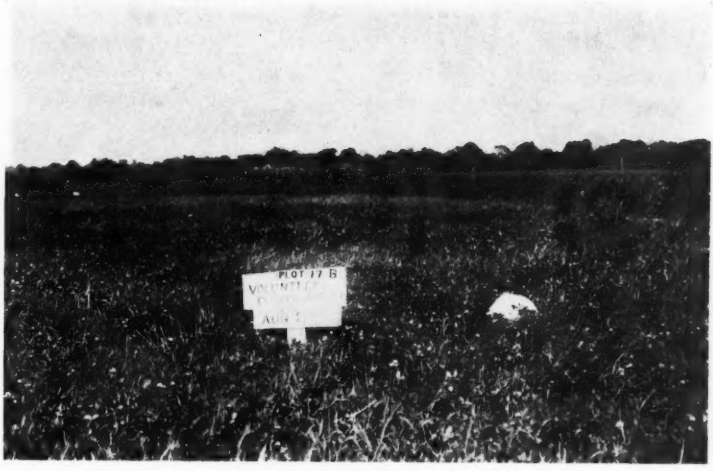

FIG. 2

ABSTRACTS OF SOME PAPERS ON SOILS PUBLISHED IN ITALIAN JOURNALS[1]

ROVIERA, P. 1924. *About Rehmsdor's Nitrogenous Fertilizer. In* Le Stazioni Sperimentali Agrarie Italiane, v. 57, no. 1–3, p. 77–81.

It is known that Nitrogenina, a soluble organic nitrogenous fertilizer, is made up of animal residues (hides, bones, blood, etc.) which were rendered soluble by a special process.

The nitrogen content is 6.96 per cent; 6.80 per cent in organic form, and 0.16 per cent in the form of ammoniacal nitrogen. Traces of nitrates also are present. In addition it contains 17.60 per cent of mineral matter and traces of phosphoric acid and potash.

Both from analyses and from pot experiments with wheat, the author concludes that Nitrogenina is a carefully prepared commercial product; however, it decomposes more slowly than bloodmeal, and its fertilizing effect will therefore be correspondingly slower.

BULLI, MARIO, AND FERNANDEZ, LORENZO. 1924 *A Rapid Method for the Determination of Potash in Agricultural and Industrial Materials. In* Giornale di Chimico Industriale ed Applicata (Milan) Ann. 6, no. 2, p. 60–62.

The volumetric method proposed for the determination of potash, is based on the formation of the compound $K_2Pb(Co(NO_2)_6)$.

In this form, under definite conditions of procedure, potassium will precipitate completely and can be determined indirectly by determining the nitrous acid with $KMnO_4$.

This method, in comparison with the others in use, offers the advantage of accuracy, speed and economy of reagents, and, in many cases can be employed with the elimination of a good part of the lengthy procedure usually necessary in potash determinations. It should be applicable to the analysis of mineral waters, potassic salts, ashes, beet pulp, molasses, guanos, manures, soils and wine.

PEROTTI, R., AND GRANDIS, G.—*Concerning the Determination of the Nitrifying Power of Agricultural Soils. In* Rend. Acc. Lincei, v. 33, s. 5, (sem. 1), no. 10.

The authors used the inoculated solution method, with a definite weight of soil, and followed in the main the procedure laid down by Barthel.[2] The

[1] These abstracts were prepared by G. Rossi, Royal Agricultural High School in Portici, Naples, Italy, and translated by S. Lomanitz, New Jersey Agr cultural Experiment Stations.

[2] Barthel, Chr: 1909 Bodenbacteriologische Untersuchungen. *In* Centbl. Bakt. (etc.), Abt. 2, v. 25, p. 108.

experiments were arranged with a view to find the optimum of the following conditions:

1. Weight of soil employed
2. The use of minimum quantities of soil
3. The period of incubation
4. Aeration of the culture
5. The time of taking the sample

They conclude from their experiments that the following are the optimum conditions under which the solution method can be used for determining the nitrifying power of the soil.

Fifty cubic centimeters of a solution containing 2 parts per thousand each of ammonium sulfate and bipotassium sulfate, is introduced into a 100-cc. flask containing 1 gm. of powdered magnesium carbonate, arranged in little heaps so as not to be completely covered by the liquid. One gram of the soil to be tested is added and incubation carried on in a thermostat at 20–25°C. for 25 days. The figure for each sample is obtained by taking the average of quadruple cultures. After washing the residue, the nitrates are determined in the filtrates from the cultures, with the sulfuric reagent.

D'Ippolito, G. 1923 *Experimental Studies on the Fertilizing Effect of Sulphur. In* Le Stazioni Sperimentali Agrarie Italiane, v. 56, no. 10–12, p. 512–520.

The experiments made by the author, which were carried on both in the greenhouse and in the field, had for their main object to find out whether sulfur fertilization exercises a favorable effect in the presence of organic matter.

Glass cylinders of 1-liter capacity were used in the greenhouse, and were filled either with sand or with soil. The first (containing sand) were impregnated with a nutrient solution (the second with water), and wheat seedlings as uniform as possible, were transferred to the cylinders. The sulfur was added in quantities of 0.50, 1.00 and 1.50 gm. per liter.

The plants treated with sulfur did not lodge, grew better and showed a greener color than the others. The weight of the seeds as well as the height of the plants was greater with the application of 0.50 gm. of sulfur per liter than with the other applications; but even with the latter, these values were greater than the corresponding ones of the check.

In the field, four plots of 45 sq. m. each were used and 15 kgm. of sulfur were applied to two plots. All the four plots were located on a soil of the same past cropping history, and received the same cultivation and fertilizer treatment. The plants on all the plots developed luxuriously, but the two sulfur plots were conspicuous by a greener color, and gave a yield at the rate of 33.76 quintals per hectare, while the check plots produced only at the rate of 30.23 quintals per hectare.

The author advocates the use of 250–300 kgm. of sulfur per hectare, but advises to ascertain the quantity already present in the soil before making sulfur applications, in order to avoid adding quantities that may prove harmful.

PRATOLONGO, U. 1922 *Concerning the Reaction of Italian Soils With Especial Reference to the Soils of Lombardy. In* Annali Instituto Agrario Ponti, 1920–22, p. 229.

The author has compiled in numerous tables the results of the analyses of 500 samples of soil, collected from the various Italian provinces. The following data are given for each sample: location, site, crops or natural vegetation, percentage of the coarse particles and of the finer soil, the reaction, total acidity, organic matter, total nitrogen, calcium carbonate, carbon dioxide and total phosphoric acid (P_2O_5).

He makes use of Wherry's classification, according to which soils fall into one or the other of the following groups: peracid, acid, subacid, neutral, subalkaline, alkaline, and peralkaline.

From the tabulated data it appears that the soil reaction stands out quite distinctly as a dominant factor of chemical fertility.

Soils of highest and conspicuous fertility show a pH value of 6.6–7.8. The nitrogen in these soils varies from 0.30 to 4.40 per thousand, without such variation indicating any essential changes in the character of the chemical fertility of the soils.

Variations of a similar nature and yet independent of the state of the chemical fertility of the soil, are noted also with respect to the content of total phosphoric acid. On the other hand, when the pH value falls below 6.4 and oscillates between 4 and 5, the fertility falls to the lowest limits.

The variations in the usual fertility elements, not only deviate from the direction of the fertility of the soil proper, but rather follow to a certain extent in an opposite direction. Thus, for instance, in the Lombardian heath even where the acidity is high and the soil fertile, the nitrogen content may easily reach the figures of 3, 4 and 5 per thousand. In the cultivated peats, the nitrogen content may even run up to 10 to 15 per thousand, without this fact constituting a condition of special fertility.

The relation between the reaction of a soil and its content in calcium carbonate, deserves to be given special attention. Soils with a particularly high acidity (pH less than 6), usually contain no calcium carbonates. This is obviously due to the inhibitive action of this compound upon the acidification of the soil. A high acidity of a soil is therefore incompatible with the presence of lime, except in small quantities and of coarse structure. Dolomite seems to be less efflcient in this respect, and so it happens that a soil from Friuli showed a pH value of 5.4 and yet contained 2.85 parts per thousand of carbonates, expressed as calcium carbonate; the carbonates however were preseht in the form of dolmite and not in that of calcite.

Slight degrees of acidity (between 6 and 7) also go with a moderate supply of calcium carbonate in the soil.

From the data of these tables it is further noticeable that the same degree of alkalinity, e.g., 8.2, may be shown by two soils, one of which contains 1.04 per cent, while the other contains 82.8 per cent calcium carbonate. Similarly, an alkalinity of pH 8.0 is noticed in two soils, with a calcium carbonate content of 3.54 and 60.5 per cent, respectively.

An alkalinity of pH 8 is also noted in the case of a soil devoid of calcium carbonate; an alkalinity of pH 7.6 in a soil with 71.2 per cent of carbonate, and an alkalinity of pH 7.5, in a soil with 65.2 per cent carbonate.

From all this, it appears that it is not safe to make assumptions as to the alkalinity of a soil on the basis of the amount of calcium carbonate it contains. Such predictions possess only a certain degree of probability, and serious errors are by no means precluded.

Chemico-agricultural relationships of considerable importance exist between the degree of acidity or alkalinity of a soil and its content of soluble nitrogen, phosphoric acid and potash.

PEROTTI, R., AND AURELI, F. ——. *Concerning the Ammonifying Power of Agricultural Soils. In* Rendiconti Accademia dei Lincei, v. 33, s. 5 (sein I), no. 10.

In a previous note one of the authors[3] specified the conditions which are most favorable for the determination of the ammonifying power of agricultural soils by the nutrient solution method. The present study was undertaken in order to apply the method to a large number of determinations, with a view first, to find out whether there will be revealed appreciable differences in ammonifying power of different soils and under different conditions, and second, to see what, if any, relationship exists between the data furnished by this method and those obtained from vegetation tests. The ultimate purpose was to establish definitely what intrinsic value may be attributed to the solution method as a means of measuring the microörganic properties of the soil, and as a result thereof, either to accept this method, to modify it, or to propose new methods.

The series of experiments, the results of which are here reported summarily, had for their object to answer the first part of the proposed problem, namely, to show the differences in ammonifying power under various conditions, as revealed by the solution method. Studies were therefore required with respect to the following points:

1. The kind of soil
2. The season of the year
3. The state of cultivation of the soil

[3] Perotti, R.: About the determination of the ammonifying power of agricultural soils. *In* Rend. Acc. Lincei, v. 29, s. 5 (sem. I), no. 6.

The method used may be summarized as follows: 10-cc. portions of a 1.5 per cent solution of Witte's peptone are introduced into test tubes, which are sterilized and then inoculated with 5 cc. of a suspension containing equal weights of water and of the soil to be tested; the test tubes are incubated at 20–25°C. for 4 days, at the end of which ammoniacal nitrogen is determined by distilling with magnesium oxide.

The authors conclude that the solution method for determining the ammonifying power of the agricultural soil, shows soils to differ appreciably in this respect, the differences running parallel to the crop-producing power. It remains however, to establish this relationship on a more definite basis. For the present it may be stated that in normal soils (by which is to be understood soils with an alkaline reaction) the capacity of producing ammonia in a micro-biochemical way, is generally sufficient for the needs of crops.

Investigations are being carried on to establish the course of this process in soils of an acid reaction.

D'IPPOLITO, G. 1923. *Recent Studies and Observations Concerning the Action of Manganese upon Plant Growth. In* Le Stazioni Sperimentali Agrarie Italiane, v. 56, no. 7–9, p. 386–400.

The author states that the erstwhile skeptical attitude toward the fertilizing value of manganese, has in recent years given place to one of greater confidence. This is due to the very good, positive experimental results obtained. He describes his own experiments, which were conducted with soil, with sand, and with animal charcoal. He first determined the manganese present in those materials, by treating them with nitric acid and lead dioxide and then adding 5 per cent acetic acid to the solution. The acetic acid proved to be most effective in bringing manganese salts into solution. He maintains, supporting his opinion by argumentation and the results of chemical tests, that very probably, the soluble manganese is present in the soil in the form of an oxide, while the insoluble manganese compounds exist in the form of silicates. Manganese fertilization should be practiced when no soluble manganese is present. The nature of the crop in question as well as the quanity of manganese suitable for the particular plant, should also be taken into consideration. (Some plants may utilize certain manganese salts, while other plants may not be able to do so.)

The author's experiments were carried on both in the laboratory and in the field. In the first case, use was made of glass cylinders of 1 liter capacity, wrapped in black paper. The following three series were arranged:

a. 9 cylinders containing animal charcoal
b. 7 cylinders containing river sand
c. 7 cylinders containing ordinary soil

To one group of 4 cylinders of the first (charcoal) series, maganese dioxide was added in portions of 0.25, 0.50, 0.75 and 1.00 gm. to another group of 4

cylinders, manganese sulfate was added in portions of 0.10, 0.25, 0.50, and 0.75 gm. The ninth cylinder was left as check.

On the second (sand) series, one group of 3 cylinders was treated with manganese dioxide in portions of 0.25, 0.50, and 0.75 gm.; another group of 3 cylinders received manganese sulfate in portions of 0.10, 0.25, and 0.50 gm.; the remaining cylinder serving as check.

The third series received the same treatment as the second.

The cultures were prepared as follows: A Knop nutrient solution, ten times normal strength, was made up; 200 cc. of this solution was used for each cylinder of the carbon and the sand series, and the proper amount of manganese dioxide or sulfate added. As many liters of carbon or sand was treated with the solution as was needed to fill the cylinders; 150 cc. of distilled water was then added to each cylinder. In this manner the dioxide and the sulfate were uniformly distributed throughout the contents of the cylinders, each of which contained a quantity of nutrient salts double that found in a liter of normal solution; in addition there was in all the cylinders the same degree of moisture.

The soil cultures were prepared by impregnating just as many liters of soil with 250 cc. of ordinary water to which the proper amount of the dioxide or sulfate of manganese was added.

Two wheat seedlings previously sprouted in a germinator, were planted in each cylinder.

These experiments showed that manganese, whether in the form of the oxide or the sulfate, was in general favorable to the plants in question. This held true in relation to the height of the plants as well as to the dry weight of stem, leaves and roots. The most remarkable results however, were obtained in the case of the charcoal series. Here, the action of the manganese, possibly on account of the special character of the medium, was especially conspicuous. A gradual increase, almost in mathematical progression, took place up to the optimum, which while not very sharply defined, corresponded to the maximum application of the dioxide and to the minimum application of the sulfate.

In the field, two plots of 425 sq. m. each, of which received 5.50 kgm. of manganese (at the rate of 120 kgm. per hectare), produced 34.23 (hectoliters? Tr), of wheat per hectare while the two check plots produced only 30.23 per hectare.

The author ascribes to manganese an oligodynamic action, and suggests that before making a manganese application to a given soil, small-scale tests with limited amounts should be carried out.